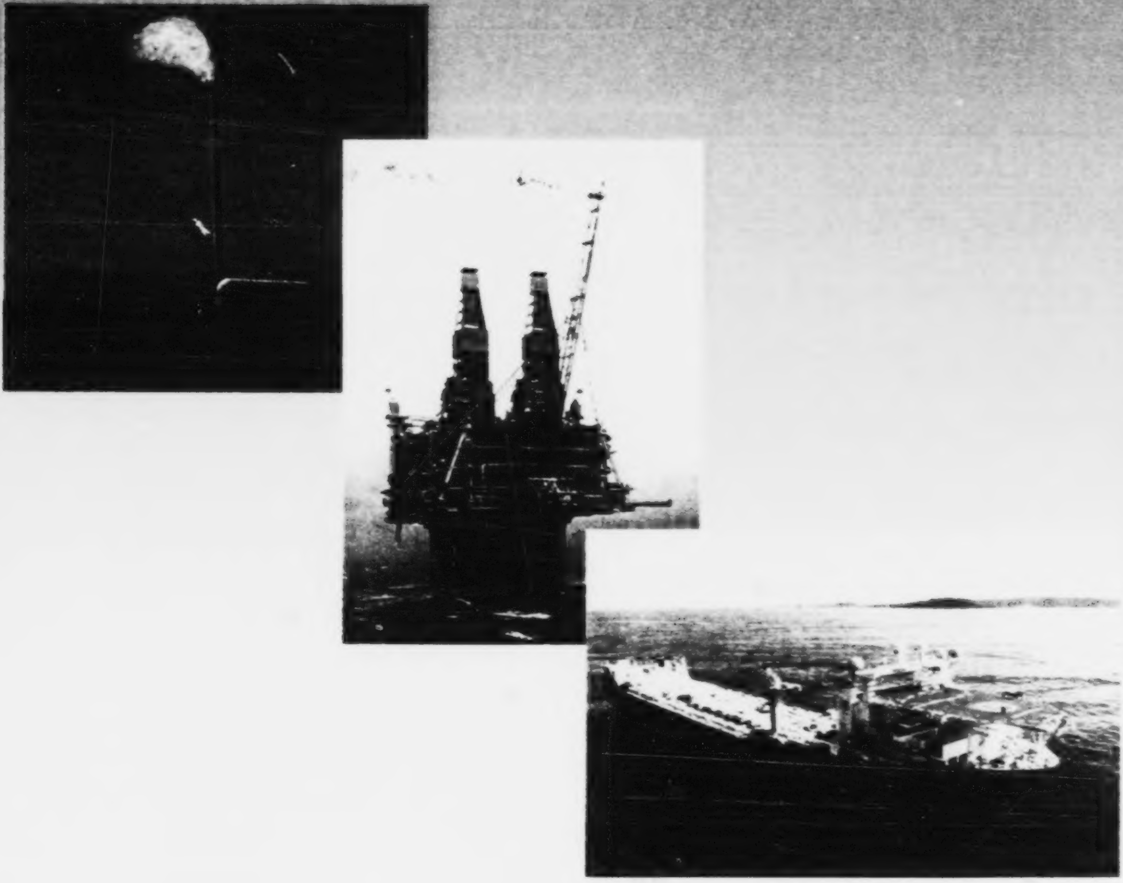
SEDIMENTARY BASINS
AND
HYDROCARBON POTENTIAL
OF
NEWFOUNDLAND AND LABRADOR



GOVERNMENT OF NEWFOUNDLAND AND LABRADOR

Department of Mines and Energy

Energy Branch

Report 2000-01

LEGEND

□ Sandstone

▨ Basement

▨ Volcanics

■ Carbonate

⁘ Pebbly Sandstones in braided stream

■ Salt

〰 Unconformity

▤ Shales & Siltstones are identified and represented by a variety of colors

-●- Proven Source Rock

-○- Possible Source rock

● A reservoir that has flow tested oil or natural gas

○ A formation known to have porosity and permeability that has not flow tested oil or gas

● Oil Zone

☼ Gas Zone

This legend applies generally to figures throughout this report. Additional legend information is provided in individual figures where required.

Well Symbols

⊕ Abandoned Oil Well

◒ Oil Show

○ Dry & Abandoned

◒ Gas Show

✳ Gas Well

● Oil & Gas Show

✳ Oil and Gas Well

Abbreviations used:

NGL - Natural Gas Liquids

C-NOPB - Canada-Newfoundland Offshore Petroleum Board

GSC - Geological Survey of Canada

FPSO - Floating Production Storage and Offloading Vessel

NHOC - Newfoundland Hunt Oil Company

PCP - Pan Canadian Petroleum Company

PAP #1 - Port au Port #1
mmcf/d - million cubic feet per day
bopd - barrels oil per day

Cover Photos:

- Flare at Port au Port #1
- The Hibernia Platform
- The Terra Nova FPSO

103-03878/

Sedimentary Basins and Hydrocarbon Potential

Foreword

The purpose of this report is to provide information on the geology and petroleum potential of selected sedimentary basins in the Newfoundland and Labrador offshore and onshore areas. The report is, for the most part, based on a review of previously published and unpublished geologic literature including government reports, journal articles and publicly available industry reports. Seismic data is reinterpreted, where appropriate, to provide new play concepts as well as emphasize known but untested targets. Maps and cross-sections are presented to provide the reader with a quick look at selected basins with particular emphasis on petroleum source, reservoir and trapping potential. Regional seismic lines and cross-sections are included to illustrate basin structure and play types, but for detailed geology, the reader is referred to the bibliography, and to the industry reports publicly available through the Canada-Newfoundland Offshore Petroleum Board (C-NOPB). Information presented is current to May 2000.

ACKNOWLEDGMENTS

This report was prepared by the Petroleum Resource Development Division (PRDD) of the Newfoundland and Labrador Department of Mines and Energy (DME). Regional interpreted seismic lines in the Whale, South Whale and Bonnition basins were provided by the Geological Survey of Canada. Additional interpretation of these lines was carried out by geophysical consultant Ian Atkinson and Phonse Fagan of the Department of Mines and Energy. The History of Exploration (up to 1984) was based on a 1984 speech by Martin Sheppard of the C-NOPB. The rest of the text was prepared by Fagan and Atkinson with selected contributions by Ian Knight. Figures were drafted by students Jason Nash, Corinna Basha and Mike Winsor, and by Lisa Clarke and Donna Taylor of DME. Anne Lake of PRDD typed the text and Tracy English of the Petroleum Projects Monitoring Division (DME) assisted in the layout. Lisa Clarke formatted the report for publication. Pictures of the Hibernia platform were provided by the Hibernia Management and Development Company; the Terra Nova FPSO by Petro-Canada; and the photograph of the Port au Port #1 flare was taken by Donna Taylor. Thanks are extended to: Iain Sinclair of the Hibernia Management and Development Company; Don McAlpine, Phil Moir and Sonya Dehler of the Geological Survey of Canada; Neil DeSilva, Judith McIntyre, Glen Power, Trevor Bennett, Paul Rideout, Sheila Duff and Judy Ryall of the Canada-Newfoundland Offshore Petroleum Board; Jim Wright and Rick Hiscott of Memorial University; Ian Knight and Gerry Kilfoil of the Newfoundland and Labrador Geological Survey; Cabot Martin of Deer Lake Oil and Gas; and Patrick Laracy of Vulcan Minerals for valuable assistance in the gathering of information. David Hawkins, Director of the PRDD was a source of constant guidance and critical information from start to finish. Special thanks are extended to Ian Knight, Iain Sinclair, David Hawkins, Neil DeSilva, Phil Moir, Chris Pereira and Hans Wielens for their critical reviews.

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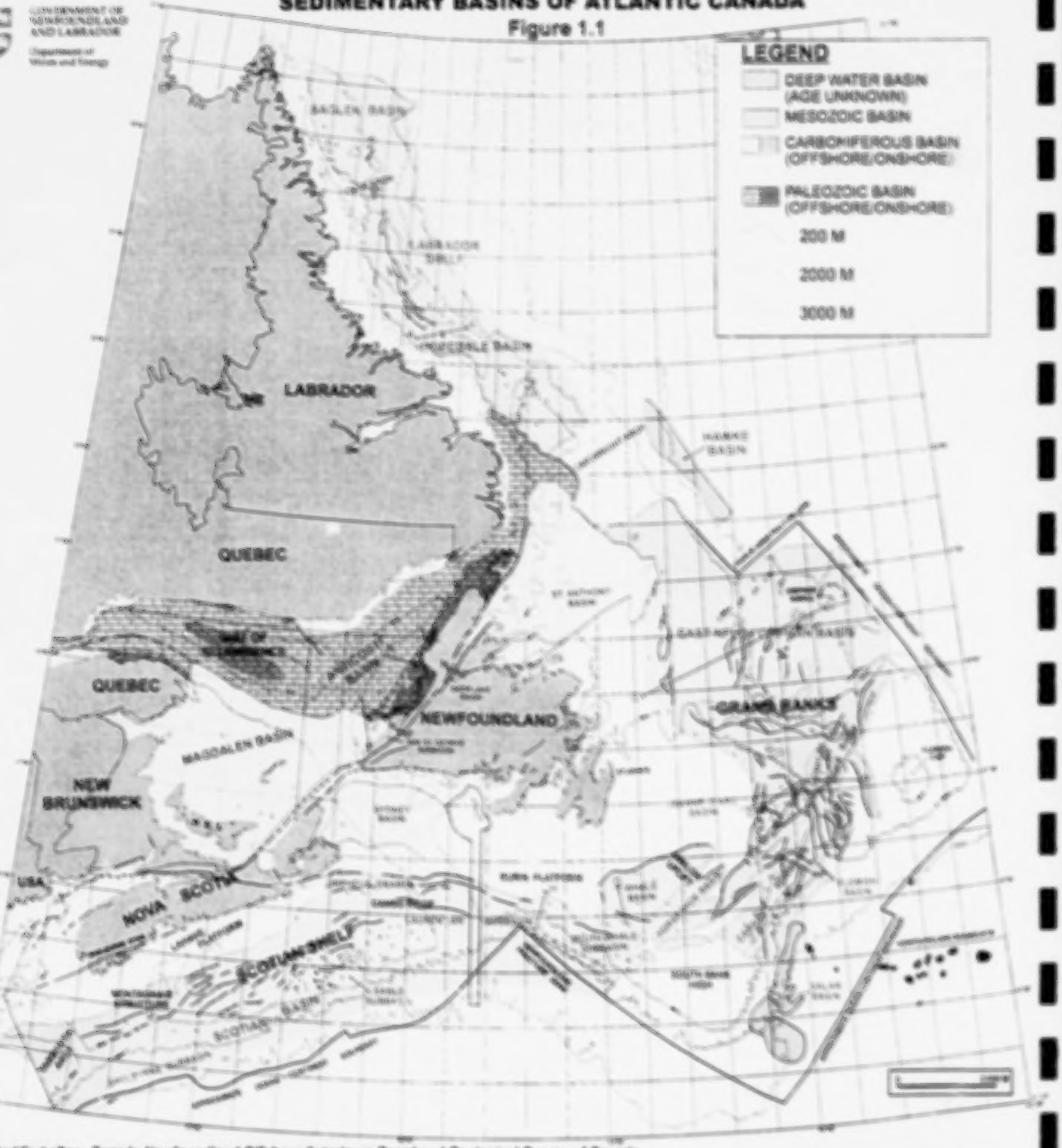
Mines and Energy

SEDIMENTARY BASINS OF ATLANTIC CANADA

Figure 1.1


LEGEND
DEEP WATER BASIN (AGE UNKNOWN)
MESOZOIC BASIN
CARBONIFEROUS BASIN (OFFSHORE/ONSHORE)
PALEOZOIC BASIN (OFFSHORE/ONSHORE)
200 M
2000 M
3000 M
SAGLEK BASIN
LABRADOR SHELF
HOPEDALE BASIN
LABRADOR
QUEBEC
HAWKE BASIN
ST ANTHONY BASIN
EAST NEWFOUNDLAND BASIN
GRAND BANKS
NEWFOUNDLAND
QUEBEC
MAGDALEN BASIN
NEW BRUNSWICK
SYDNEY BASIN
USA
NOVA SCOTIA
SCOTIAN SHELF
SCOTIAN BASIN
SABLE SUBBASIN
BURIN PLATFORM
WHALE BASIN
SOUTH BANK HIGH
SALAR BASIN
JEANNE D'ARC BASIN
FLEMISH BASIN

odified after: Canada-Newfoundland Offshore Petroleum Board and Geological Survey of Canada

This map outlines the Paleozoic and Mesozoic cover of eastern Canada. The Labrador Shelf outline is based on the GSC's Basin Atlas map of the Lower Tertiary Cartright Shale. The locations of cross-sections presented in this report are also shown.

Section 1
Introduction

Although still in the early stages of exploration, the east coast of Canada, including offshore Nova Scotia and offshore Newfoundland and Labrador, has recently come to prominence as a major new territory of petroleum production. The Sable gas project, offshore Nova Scotia, is currently producing about 400 mmcf/d from a multi-field development near Sable Island. The Hibernia field, on the Grand Banks of Newfoundland, began production from a gravity based structure in November 1997 and is now producing about 180,000 barrels per day (figure 1.2). Thirty five kilometres south of Hibernia, the Terra Nova field will begin production in March 2001 using a floating production storage and off-loading system (FPSO), and is expected to produce about 125,000 barrels per day at start up. Husky Oil recently announced a development proposal to produce 75,000 to 100,000 barrels per day from the White Rose field by late 2003, and Chevron is currently studying the possibility of bringing the Hebron/Ben Nevis fields into production. Based on these four developments alone, offshore Newfoundland will likely to be producing about 500,000 bopd by mid-decade.

Figure 1.2

The Hibernia Platform on the Grand Banks commenced production in November 1997.

In Newfoundland and Labrador, petroleum exploration has focused primarily on the Mesozoic basins off the Province's east coast. However, during the last decade, exploration has also occurred in the Paleozoic rocks of western Newfoundland (figure 1.1). To date, 125 exploration wells, 31 delineation wells and 27 development wells have been drilled offshore Newfoundland and Labrador. Technically recoverable resources of 2.1 billion barrels of oil, 9.3 trillion cubic feet of natural gas and 413 millions barrels of Natural Gas Liquids (NGL) have been discovered (table 1.1). The international petroleum industry, along with local companies and research institutions, has successfully adapted technologies developed in the North Sea, Gulf of Mexico and elsewhere to meet the challenges of the northwest Atlantic environment in a manner that provides for safe and profitable access to the area's extensive petroleum resources.

All of the major oil discoveries, thus far, are located in the Jeanne d'Arc Basin which covers an area of about 14,000 square km. The Hibernia, Terra Nova, White Rose and Hebron/Ben Nevis fields contain an estimated 1,978 million barrels of recoverable oil and 4050 bcf of natural gas and 266 million barrels of NGL (C-NOPB, 2000). Undiscovered resources studies have focused primarily on the Northern Grand Banks and have resulted in estimates ranging from 6 to 12 billion barrels of recoverable oil. These estimates will probably change significantly as further drilling occurs, and new areas and play concepts are explored. As evidenced by figure 1.1, the Jeanne d'Arc Basin constitutes but a small part of the Mesozoic cover off Newfoundland and Labrador. Significant oil and gas shows have also been encountered in several other lightly drilled Mesozoic basins, as well as within the Paleozoic rocks of western Newfoundland.

Petro-Canada has estimated it's finding costs for the Jeanne d'Arc Basin at less than US$1.00/bbl and extraction costs for the Terra Nova Field at US$ 7.50 per barrel. This extraction cost is based on a reserve of 370 million barrels although the company estimates that an additional 100 million barrels is likely to be present in an undrilled fault block on the east side of the field.

Table 1.2 presents the value of bids in recent land sales held by the Canada-Newfoundland Offshore Petroleum Board (C-NOPB). The 1999 sale saw a record total of C$192 million, with one parcel in the Flemish Pass Basin going for C$110 million. The fact that most of these work commitments are for parcels located within the Ridge Complex and Flemish Pass Basin clearly indicates that exploration is about to expand beyond the Jeanne d'Arc Basin. The Flemish Pass Basin, located in deeper waters (~1000 metres) to the east of the Jeanne d'Arc, has had only three wells drilled to date. Although all three were dry holes the limited drilling has proven the presence of the same rich Kimmeridgian source rock that occurs in the Jeanne d'Arc Basin, as well as equivalent age reservoir rocks. Also, during 1998 and 1999, large speculative seismic programs were shot in the Flemish Pass and throughout the basins of the southern Grand Banks. This, combined with the recent posting of large land blocks (see figure 1.3) in the Carson, Bonnition and South Whale basins is a further indication of the onset of a new round of exploration. This round will re-visit areas such as the Flemish Pass and southern Grand Banks with an improved understanding of stratigraphy and trapping mechanisms, and will be bolstered by the major advances in subsurface mapping provided by 3D seismic data.

Significant Discoveries - Discovered Resources

Discovered Resources **Newfoundland Offshore Area**

	Oil		Gas		NGL's	
Field Name	$m^3 \times 10^6$	MMBbls	$m^3 \times 10^9$	bcf	$m^3 \times 10^6$	MMBbls
Hibernia	140.5	884	38.7	1375	23.0	145
Terra Nova	64.6	406	7.6	260	2.2	14
Hebron	51.6	325	-	-	-	-
White Rose	43.5	274	59.0	2091	12.2	77
West Ben Nevis	5.4	34	-	-	-	-
Mara	3.6	23	-	-	-	-
Ben Nevis	8.7	55	8.9	315	4.7	30
North Ben Nevis	2.9	18	3.3	116	0.7	4
Springdale	2.2	14	6.7	238	-	-
Nautilus	2.1	13	-	-	-	-
King's Cove	1.6	10	-	-	-	-
South Tempest	1.3	8	-	-	-	-
East Rankin	1.1	7	-	-	-	-
Fortune	0.9	6	-	-	-	-
South Mara	0.6	4	4.1	144	1.2	8
North Dana	-	-	13.3	472	1.8	11
Trave	-	-	0.8	30	0.2	1
West Bonne Bay	5.7	36	-	-	-	
Sub-Total (Grand Banks)	**336.3**	**2117**	**142.4**	**5050**	**46.0**	**290**
North Bjarni	-	-	63.3	2247	13.1	82
Gudrid	-	-	26.0	924	1.0	6
Bjarni	-	-	24.3	863	5.0	31
Hopedale	-	-	3.0	105	0.4	2
Snorri	-	-	3.0	105	0.4	2
Sub-Total (Labrador Shelf)	-	-	**119.6**	**4244**	**19.9**	**123**
Total	**336.3**	**2117**	**262.0**	**9294**	**65.9**	**413**

Source: C-NOPB

Table 1.1

Recent Landsale Results

Year	Number of Parcels Bid	Bids($Can Millions)
1995	1	95.8
1996	8	126.1
1997	7	97.0
1998	13	175.2
1999	5	192.3
Total	34	686.4

Table 1.2

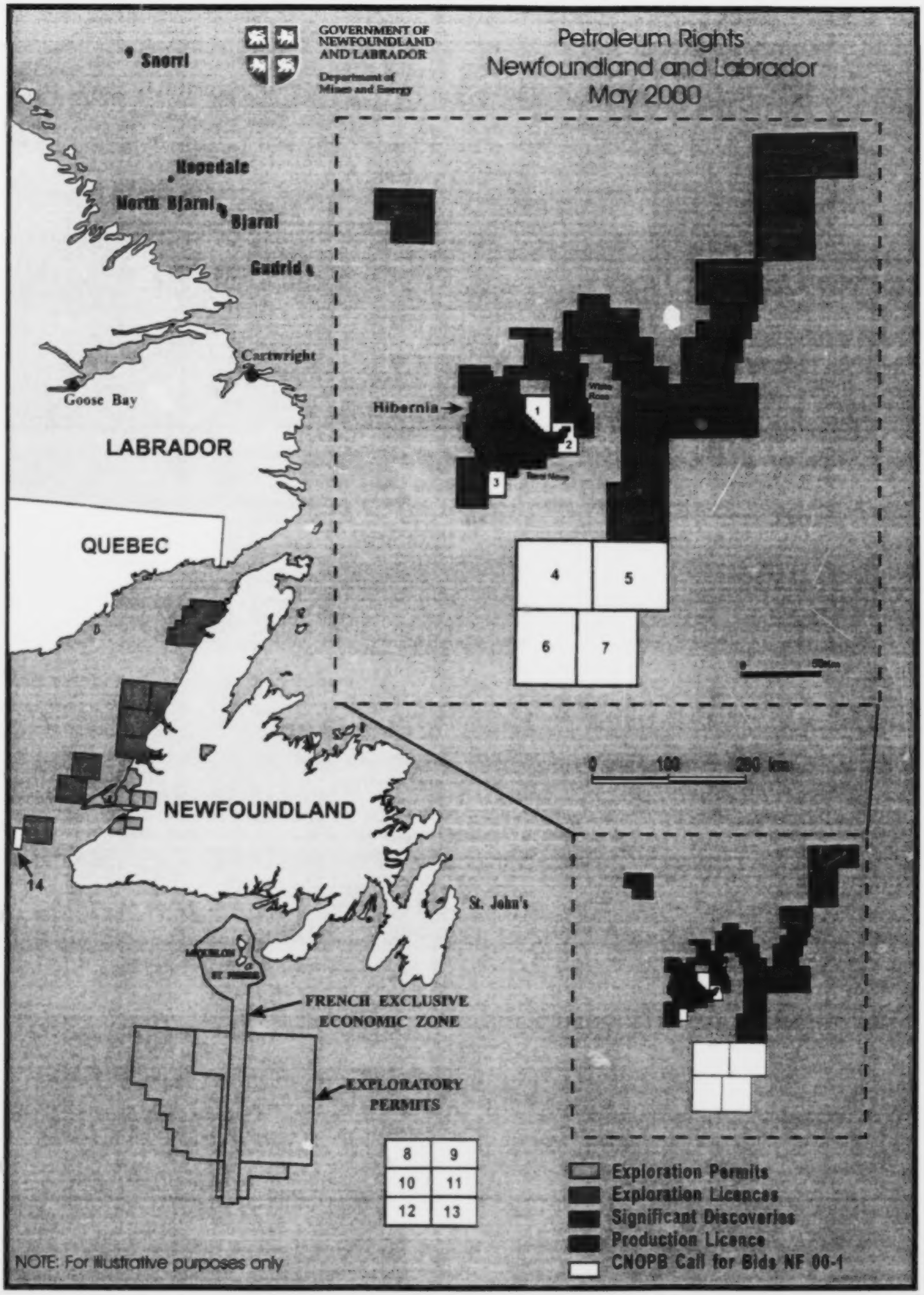

GOVERNMENT OF NEWFOUNDLAND AND LABRADOR
Department of Mines and Energy
Petroleum Rights
Newfoundland and Labrador
May 2000
Snorri
Hopedale
North Bjarni
Bjarni
Gudrid
Cartwright
Goose Bay
LABRADOR
QUEBEC
NEWFOUNDLAND
St. John's
14
Hibernia
White Rose
Terra Nova
1
2
3
4
5
6
7
8
9
10
11
12
13
0
50 km
0
100
200 km
FRENCH EXCLUSIVE ECONOMIC ZONE
EXPLORATORY PERMITS
Miquelon
St. Pierre
Exploration Permits
Exploration Licences
Significant Discoveries
Production Licence
CNOPB Call for Bids NF 00-1
NOTE: For illustrative purposes only

Figure 1.3

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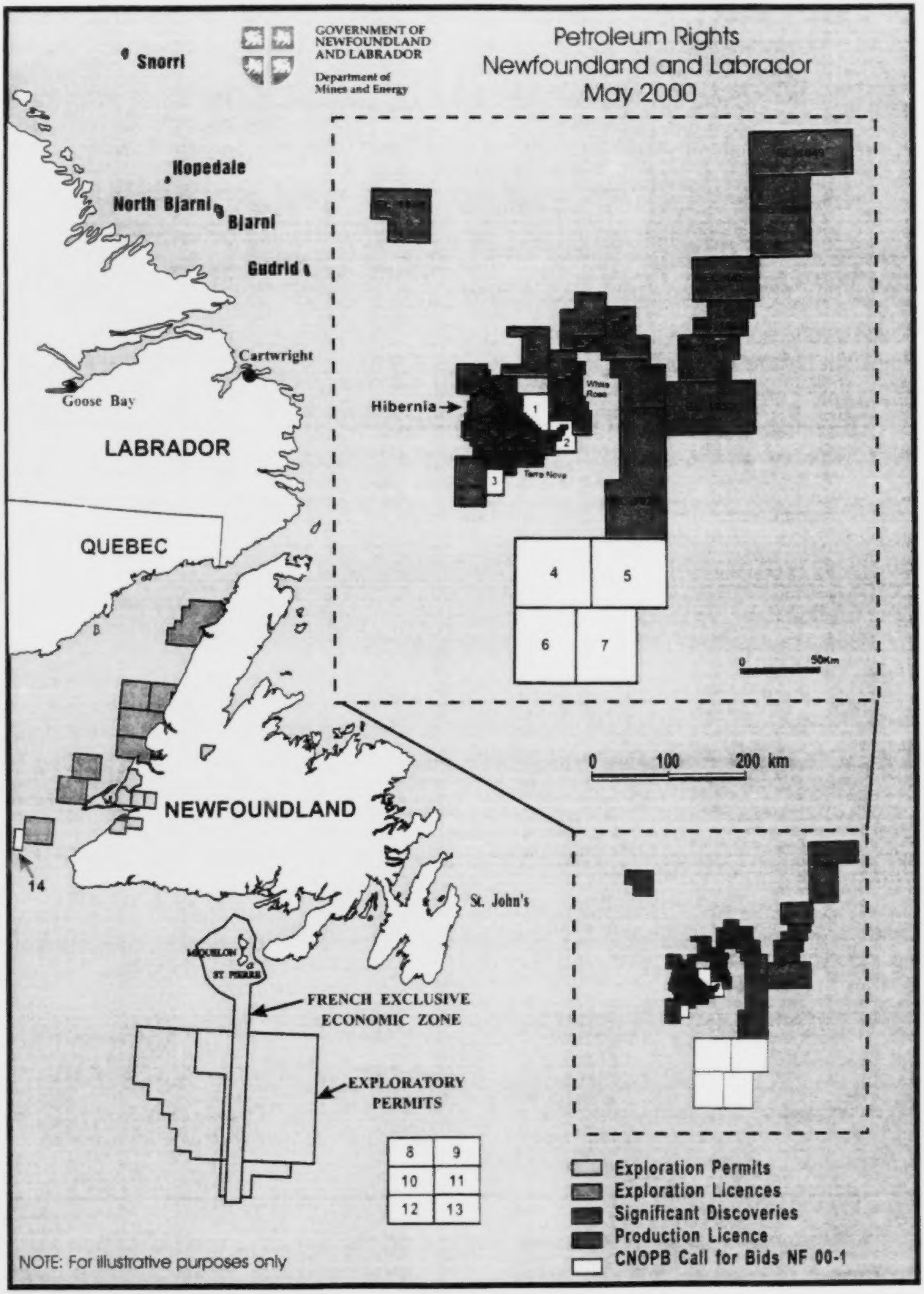
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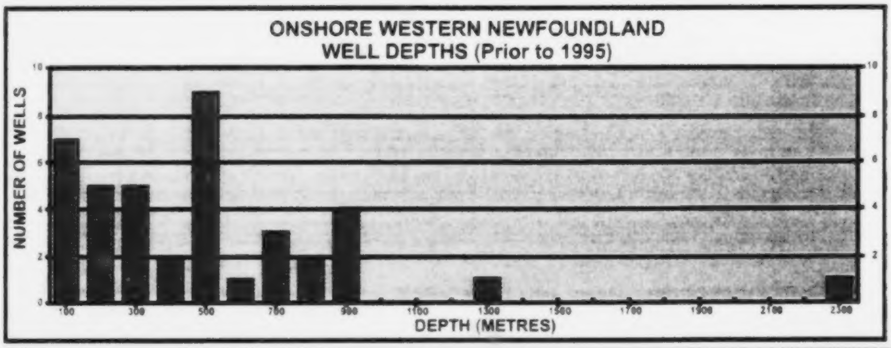
White Rose
Terra Nova
1
2
3
4
5
6
7
0
50Km
0
100
200 km
MIQUELON
ST PIERRE
FRENCH EXCLUSIVE ECONOMIC ZONE
EXPLORATORY PERMITS
8
9
10
11
12
13
Exploration Permits
Exploration Licences
Significant Discoveries
Production Licence
CNOPB Call for Bids NF 00-1
NOTE: For illustrative purposes only

Figure 1.3

Section 2
History of Exploration

Western Newfoundland

Figure 2.1



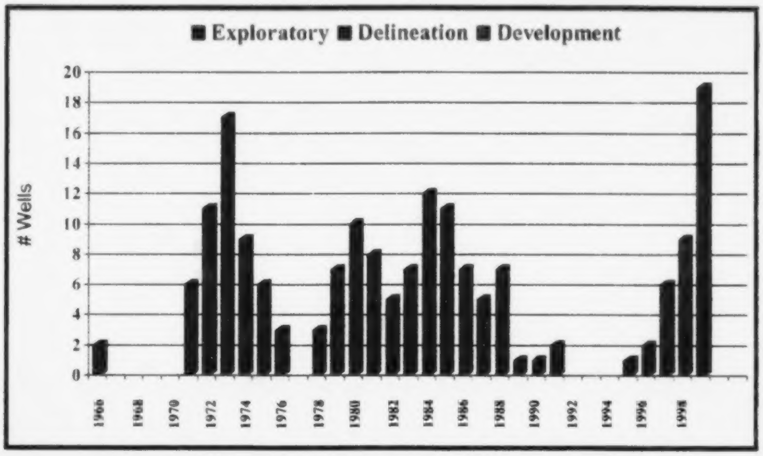
Historic drilling in western Newfoundland has been to shallow depths and did not test the deeper features now recognized from modern seismic. The deepest well shown was drilled in 1973 and all the others were drilled prior to 1966.

The Paleozoic rocks of onshore western Newfoundland were the first in the Province to be recognized as having petroleum potential. In 1812, a Mr. Parsons noticed oil floating on the surface of Parson's Pond on the Great Northern Peninsula, which he collected and used as a treatment for rheumatism. The first oil-exploration well was drilled at Parson's Pond in 1867 to a depth of 213 metres and encountered "some oil". Numerous oil seeps and shows in water wells led to the drilling of about 60 wells onshore western Newfoundland in several pulses of activity between 1900 and 1965 . Unfortunately, the drilling was carried out with poor quality equipment and insufficient financial backing to assess the area properly. Most of the wells were less than 500 metres deep (figure 2.1), with a few exceeding 700 metres, although it is now known that the sediment thickness often exceeds 3000 metres in the areas drilled. The NALCO 65-I, well drilled in 1965 at Parsons Pond, reached a depth of 1302 metres and had to be abandoned when it started to spew gas and caved in, causing the well to be terminated. This was the deepest well western Newfoundland had seen and although drilled without the benefit of seismic data came very close to penetrating a thrust slice that is now recognized from modern seismic. (More discussion of this prospect is provided in Section 8). In fact, none of the wells drilled were based on seismic mapping, and so these early explorers were essentially drilling blind and, as it turns out, too shallow. In 1995, Hunt Oil and it's partner, PanCanadian, drilled the first modern well in western Newfoundland that was based on seismic mapping. The *Port au Port #1* well was a discovery that flow-tested approximately 2000 bopd and 1.3mmcf/d of gas from a carbonate reservoir at 3400 metres depth. Follow up drilling in four additional deep wells in the Port au Port area failed to produce further discoveries and exploration activity has slowed. The legacy of the most recent round of exploration is the availability of new seismic and well data that have proven the presence of a viable petroleum system in the deeper rocks of western Newfoundland, as well as presence of several large undrilled structures.

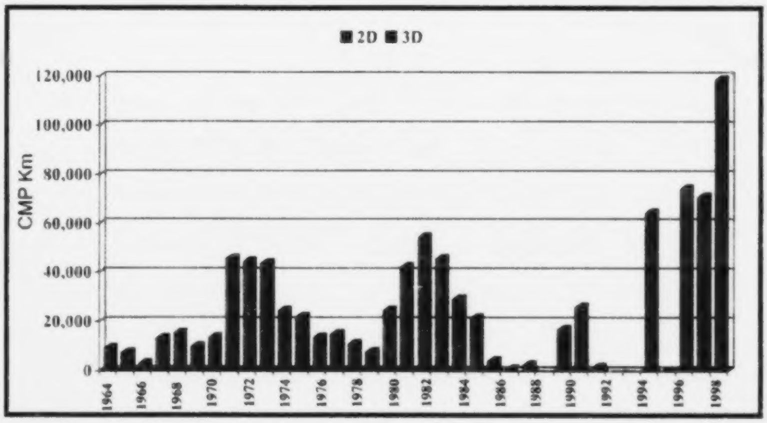
Grand Banks and Labrador Shelf

The marine geology of eastern Canada was first studied in the 17th century when seamen measured the water depths and collected bottom samples to aid in locating suitable anchorage and harbour sites. Airborne magnetometer and seismic refraction surveys conducted in the late 1950's and early 60's revealed that the offshore geology was quite different from that of the rocks exposed onshore. These findings established that sediments in excess of 4000 metres thickess blanket the Grand Banks of Newfoundland. Oil companies were quick to determine that the area could be a favourable habitat for petroleum, and consequently, the first federal offshore permits to explore for hydrocarbons were issued on Newfoundland's continental shelf in 1964.

Total Offshore Wells Drilled



Total Offshore 2D & 3D Seismic Data



C-NOPB

Figure 2.2

One year later, the land position on the Grand Banks was dominated by Amoco (then called Pan American) which held 14 million hectares. Work commitments were only 12 cents per hectare for the first 3 years on a permit's 12 year life and vast tracts of land were subsequently acquired. In 1966, Amoco and Imperial Oil drilled the first wildcat well offshore Canada. *Pan Am A-1 Tors Cove* was plugged and abandoned in Jurassic salt after encountering minor shows of methane during formation testing. Four days after the well was completed, a second well, *Pan Am Grand Falls* was spudded 170 km to the northeast. The well was a dry hole and failed to reach its projected total depth due to deteriorating weather conditions. Having drilled two dry holes, the companies stopped to reconsider their exploratory efforts. Subsequently, all drilling programs were halted for a four year period and efforts concentrated on the acquisition of reflection seismic data.

In 1971, drilling resumed on the Grand Banks as well as on the Labrador Shelf. By the end of 1974, 40 dry holes had been drilled on the Grand Banks. This lack of success combined with escalating drilling costs and a jurisdictional dispute between the federal and provincial governments over ownership of the offshore led to a reduced level of drilling offshore Newfoundland. At this time drilling was initiated in the Orphan Basin and continued off Labrador (see Appendix A). Geophysical investigations indicated the existence of a variety of favourable structures on the Grand Banks, including salt domes, basement highs and tilted fault blocks - but drilling had failed to identify commercial pools of oil or gas. However, there were some significant shows: the *Adolphus 2 K-41* well, drilled on a salt piercement structure in the Jeanne d'Arc Basin, tested minor flows of oil and solution gas from thin Upper Cretaceous sandstones; and, not far from the initial Tors Cove well, *Heron H-73* tested 22 barrels of 7" API gravity oil from an Upper Cretaceous limestone. Between 1974 and 1976, there were also three wet gas discoveries made on the Labrador Shelf - *Bjarni H-81*, *Gudrid H-55* and *Snorri J-90*.

No drilling occurred in 1977 and all three wells drilled in 1978 were located on the Labrador Shelf, but drilling resumed on the Grand Banks in 1979 with the spudding of *Gabriel C-60* in the Flemish Pass Basin. Gabriel was the first well in the Flemish Pass and, although a dry hole, proved the presence of petroleum in the basin by way of a Lower Cretaceous core that bled oil. Shortly after Gabriel had spudded, Chevron Standard farmed into a 213,000 hectare block controlled by Mobil Oil in the Jeanne d'Arc Basin. In order to meet their obligations, Chevron spudded the *Hibernia P-15* well.

When drillstem tested, the well flowed at a combined rate of 11,415 barrels per day of high quality oil and 11.2 mmcf/d of gas through a 26/64" choke. The well had an estimated flow potential of more than 20,000 barrels of oil per day making Hibernia the first field on the Atlantic Shelf of North America thought to be capable of commercial production. Under the terms of the farm-out agreement, Mobil assumed operatorship of the field. Nine delineation wells were drilled on the Hibernia structure, only one of which was a dry hole, confirming the presence of a "giant" oilfield. The discovery of Hibernia demonstrated that Cretaceous faulting had the proper timing to trap oil in the Jeanne d'Arc Basin.

Percentage Wells per Area

Total Exploration and Delineation wells drilled = 154

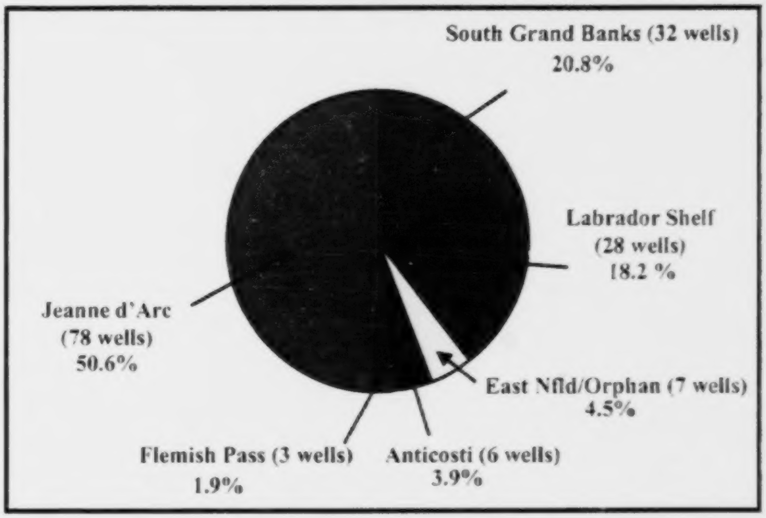


Figure 2.3

During the next six years, fourteen additional discoveries were made in the Jeanne d'Arc Basin and Ridge Complex, including Hebron (1981), Terra Nova (1984) and White Rose (1985) - setting the stage for multiple developments.

In February 1985, the jurisdictional dispute between the federal and provincial governments was resolved by means of the Atlantic Accord. This led to the establishment of the Canada-Newfoundland Offshore Petroleum Board (C-NOPB) to administer the offshore area on behalf of the governments of Newfoundland and Canada. With the Atlantic Accord in place, Mobil submitted a development plan for Hibernia in September 1985, but when oil prices dropped in 1986 plans to develop the field were put on hold. With sustained low prices, drilling gradually dropped off so that only four wells were drilled between 1989 and 1995. Nevertheless, a fiscal arrangement by which Hibernia could proceed was finalized in 1990 and construction of the Bull Arm facilities began immediately. In 1992, drydock construction of the Hibernia GBS began at Bull Arm and in November 1997, Hibernia achieved first oil production. Development drilling at Hibernia has proven that the sands of the Hibernia Formation are a better reservoir than originally anticipated and has resulted in daily production rates being increased from the initial estimate of 135,000 barrels to 180,000 barrels. The C-NOPB has also increased it's reserve estimate for Hibernia from 666 million barrels to 884 million barrels recoverable. These numbers could continue to increase as development drilling unfolds and with further delineation of the field.

The installation of the Hibernia production system on the Grand Banks put in place crucial infrastructure that is facilitating a rapid expansion of the province's petroleum sector. The 1.2 million tonne fixed platform, which was built to meet the challenges of the northwest Atlantic environment, including collision by icebergs, is essentially a concrete island 300 km from shore that is playing a supporting role for exploration and development on and beyond the Grand Banks. The sharing of warehouse space, helicopter support, and various services with other operators has simplified logistics and brought new efficiencies to exploration and development throughout the province.

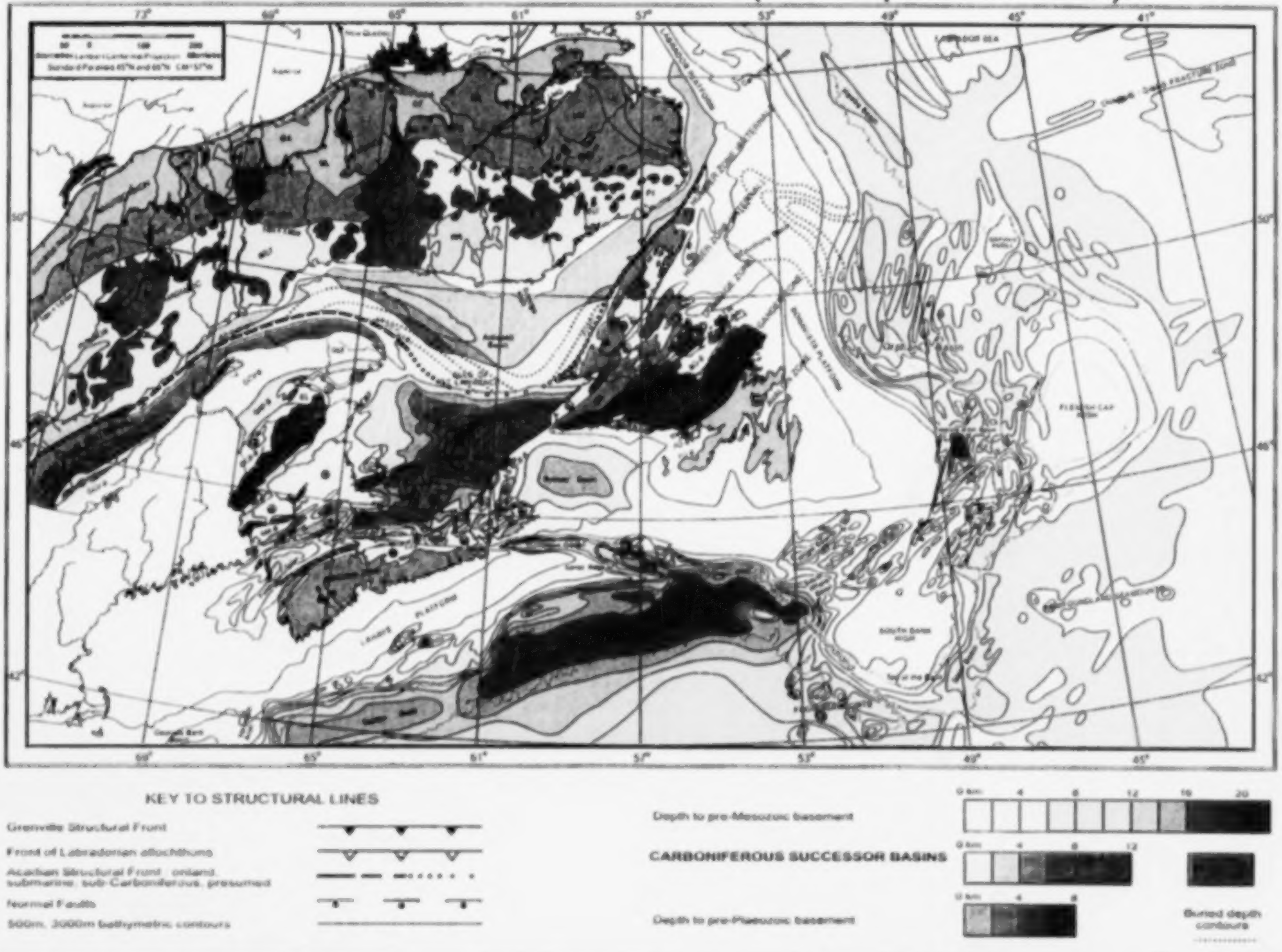
In March 2001, the 400-500 million barrel Terra Nova field will begin production at about 125,000 barrels per day using an FPSO. With the startup of Terra Nova, the Province will have gone from zero production to more than 300,000 barrels per day - about 1/3 of Canada's conventional light oil production - in just over three years. This is possible because of the high flow capacity of the

Grand Banks reservoirs (for example; individual Hibernia wells are capable of producing in excess of 50,000 bopd from the sandstones of the Hibernia Formation alone). Terra Nova will produce via subsea templates that have been installed in twelve metre deep glory holes that protect wellheads from iceberg scour. Although precautions must be taken in regard to icebergs, the probability of a berg hitting an installation is very low. When a berg does approach a drilling rig or production system it can normally be towed by supply vessels to sufficiently alter its course.

As previously stated, Husky Oil recently announced its intention to develop the White Rose field by FPSO. Chevron and partners are currently studying the feasibility of developing the Hebron/Ben Nevis fields, which the C-NOPB estimates to contain 414 million barrels of recoverable oil and 313 billion cubic feet of natural gas. Chevron has indicated that they are considering both fixed and floating systems as possible modes of development. Other smaller fields in the basin may be developed as multi-pool projects or by subsea tie-backs to the larger developments. In the meantime exploration continues.

Figure 3.1

TECTONIC ASSEMBLAGES MAP (GSC Open File 3657)


73°
69°
65°
61°
57°
53°
49°
45°
41°
50°
46°
42°
KEY TO STRUCTURAL LINES
Grenville Structural Front
Front of Labradorian allochthons
Acadian Structural Front : onland, submarine, sub-Carboniferous, presumed
Normal Faults
500m, 3000m bathymetric contours
Depth to pre-Mesozoic basement
0 km
4
8
12
16
20
CARBONIFEROUS SUCCESSOR BASINS
Depth to pre-Palaeozoic basement
Buried depth contours

This tectonic assemblages map shows depth to basement along the Grand Banks and Scotian Shelf and also illustrates the thickness of the Cenozoic wedge that progrades seaward over the shelf edge. Map provided courtesy of the Geological Survey of Canada.

Section 3
Geological Framework

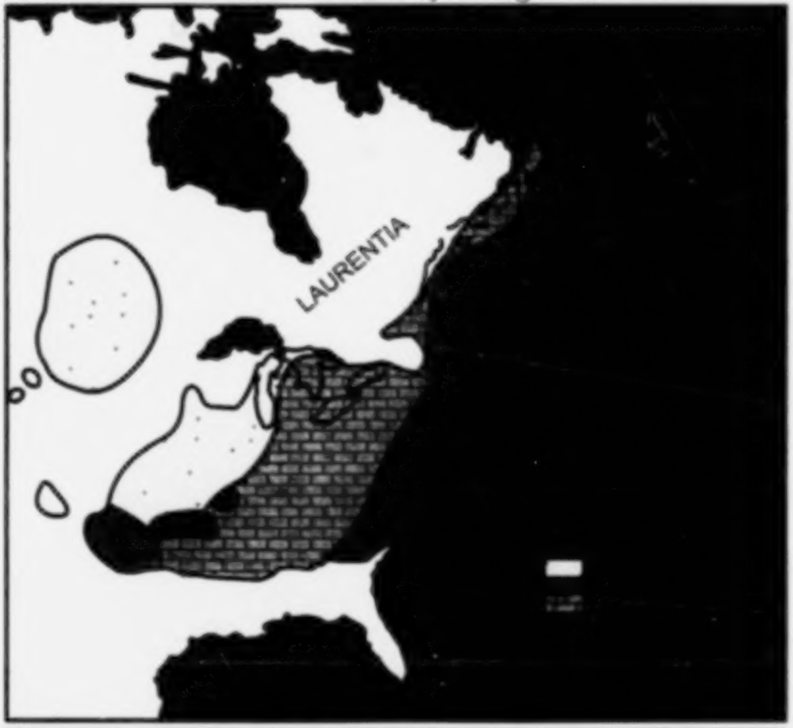
Twenty sedimentary basins and sub-basins, ranging in age from Early Paleozoic to Late Cretaceous, have been identified onshore and offshore Newfoundland and Labrador (figures 1.1 and 3.1). The early Paleozoic Anticosti Basin, which contains the oldest sediments, extends from the Gulf of St. Lawrence to the southeastern coast of Labrador where it is overlain by Mesozoic strata of the Labrador Shelf. Mesozoic sediments have been preserved as passive margin sequences along the entire outer shelf and in a series of failed rifts that trace a northeast transect across the Grand Banks. The Mesozoic basins are overlain by an undeformed Cenozoic wedge that progrades seaward over the continental slope.

Paleozoic Basins

The Early Paleozoic Anticosti Basin is one of a number of basins that preserve Cambrian to Ordovician shelf and foreland basin rocks along the broad sweep of the Appalachian trend of eastern North America (figures 3.2 and 3.3). Cambrian and Ordovician rocks of the Anticosti Basin include sandstones and carbonates that once formed part of a broad continental shelf that bordered the ancient continent of Laurentia. South of this margin stretched the wide expanse of the warm, Early Paleozoic "Iapetus Ocean" (figure 3.2). When Iapetus closed, the continental margin became deformed in a long sinuous orogenic mountain belt constituting the present day Appalachian Mountains. In present day western Newfoundland, the ancient shelf is preserved within and to the west of the External Humber Tectonostratigraphic zone (Williams, 1978, 1995; see figure 3.1) as a lightly deformed, mainly carbonate, authochthonous (non-transported) sequence. Onshore and nearshore western Newfoundland the shelf sequence is locally overlain by allochthoneous (transported) slope-to-basin sediments and ophiolites that were thrust westward by the closing of Iapetus. The transported sequence contains the Green Point Formation shale that is believed to be the source rock for the numerous oil seeps throughout the area, as well as oil and gas in the *Port au Port #1* discovery. Within the Gulf of St. Lawrence, the carbonate shelf is overlain by a relatively undeformed sequence of Silurian and Devonian clastics that were shed from orogenic sources to the east. Basins such as these in Quebec and Ontario have produced oil and gas from reservoirs in Ordovician carbonates. Southward, in Texas and Oklahoma, considerable quantities of petroleum have been recovered from large carbonate reservoirs in the Lower Ordovician

Figure 3.2

Circa 470 million years ago

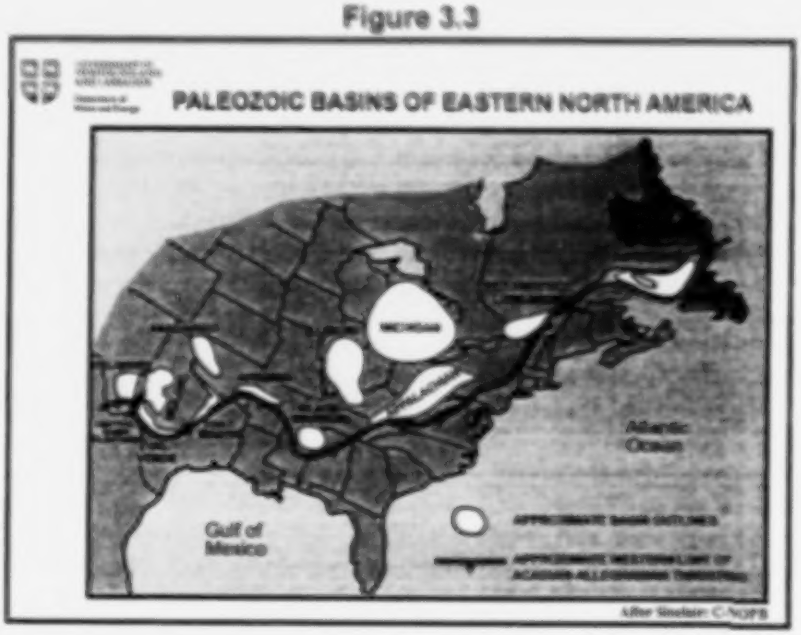


Schematic map shows early Middle Ordovician Sedimentary Facies on the Eastern Margin of North American (Modified after Dott and Batten, 1971)

Ellenburger and Arbuckle groups in the Midland, Val Verde, Anadarko, Forth Worth and Arkoma basins (figure 3.3).

Carboniferous sediments were deposited in a series of large basins that extend throughout the Maritime provinces of eastern Canada and into New England (figure 1.1). Two Carboniferous basins (the Deer Lake Basin and the Bay St. George Subbasin) are located onshore western Newfoundland. A few shallow wells drilled in these basins have yielded some significant oil and gas shows but no discoveries have yet been made in the Carboniferous rocks of Newfoundland. The Bay St. George Subbasin extends offshore into the southern Gulf of St. Lawrence where it merges with its parent Magdalen Basin (figures 1.1 and 8.1). Carboniferous sediments are also preserved within offshore basins to the south (Sydney Basin) and north of Newfoundland (St. Anthony Basin) where they are ultimately onlapped by Mesozoic strata.

Figure 3.3



After Sinclair; C-NOPB

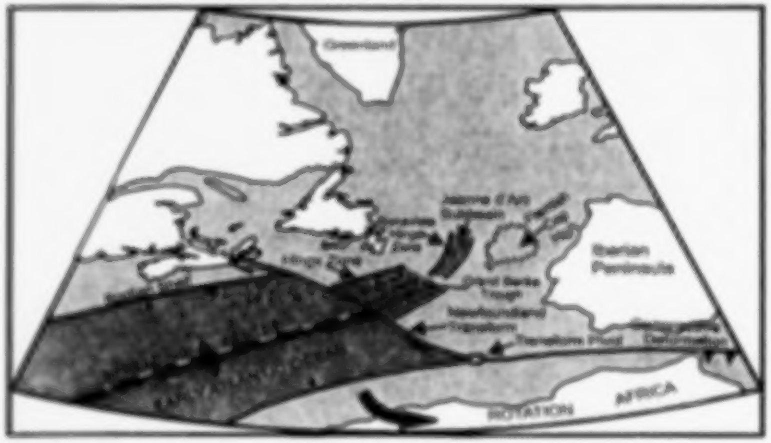
Mesozoic Basins

Mesozoic basins off eastern Canada were formed by rifting and seafloor spreading associated with the breakup of the supercontinent, Pangea. Seafloor spreading advanced from the south, reaching Nova Scotia in the Late Triassic (figure 3.4) and creating a northeast trending rift valley within the Grand Banks crustal block, known as the Grand Banks Trough. The rift failed to propagate through the continental crust of the Grand Banks, but the rift valley was eventually inundated by the proto-Atlantic and became the precursor of the Grand Banks basins. An important event in the Late Jurassic (Kimmeridgian) was a marine transgression that deposited an organic rich shale across the Grand Banks, as well as within in the basins of the North Sea. This shale, known as the Egret Member on the Grand Banks, is recognized as the primary source of the oil and gas that has been discovered in the Jeanne d'Arc Basin.

With the northward advance of rifting stalled at the Grand Banks, seafloor spreading was accommodated by strike slip movement along the Newfoundland Transform (figure 3.4.A & B). Near the end of Late Jurassic, the spreading centre stepped to the east of the Grand Banks, initiating the separation of the eastern Grand Banks from Iberia. It was at about this time, perhaps in isostatic response to the changed rift pattern (Kerr 1985), that the continental crust beneath the Grand Banks arched upwards along a fairway running southeast from the Avalon Peninsula known as the Avalon Uplift (figure 3.4.C). This led to erosion of older Jurassic sediments along the arch and separated the evolving basins of the northeast Grand Banks from those of the southwest Grand Banks. Seafloor spreading advanced northward, eventually separating Greenland from Labrador during the Early Cretaceous. The Grand Banks Trough remained tectonically active during the Early Cretaceous and became fragmented by a series of northeast trending ridges which became new sources of sedimentation. Throughout the Early Cretaceous a series of marginal marine and fluvio-deltaic sequences were deposited, including most of the proven hydrocarbon reservoirs. By Late Cretaceous, crustal cooling in the Grand Banks area led to regional thermal subsidence and the deposition of a relatively undisturbed sequence of Upper Cretaceous and Tertiary sediments across the shelf.

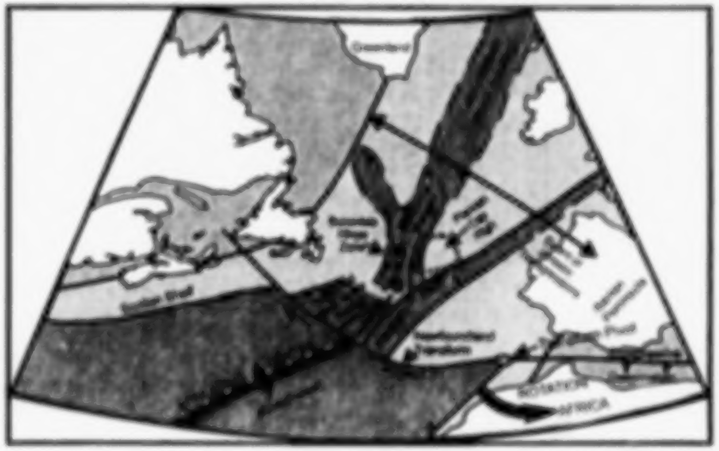
Figure 3.4

A


Greenland
Iberian Peninsula
Grand Banks Trough
Newfoundland Transform
Transform Fault
Deformation
Hinge Zone
Scotian Shelf
ROTATION
AFRICA

Late Triassic - 230 MY

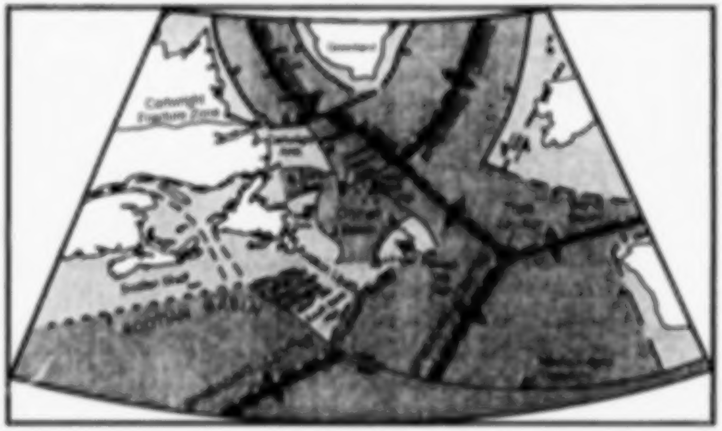
B


Greenland
Scotian Shelf
Newfoundland Transform
ROTATION
AFRICA

Mid Jurassic - 175 MY

Schematic maps depict the evolution of the eastern Canadian Mesozoic basins: In the Late Triassic the Atlantic spreading centre reached offshore Nova Scotia and created a rift valley across the Grand Banks (the Grand Banks Trough). Spreading failed to advance through the Grand Banks and eventually stepped to the east which led to the separation of the Grand Banks from Iberia. In Late Jurassic the Avalon Uplift caused the erosion of overlying and adjacent sediments and separated the basins of the NE Grand Banks from those of the SW Grand Banks. By the end of the Cretaceous the basins had fragmented into the present arrangement and had entered the passive drift phase whereby they were overlain by a thick progradational wedge of undisturbed Cenozoic sediments.

C

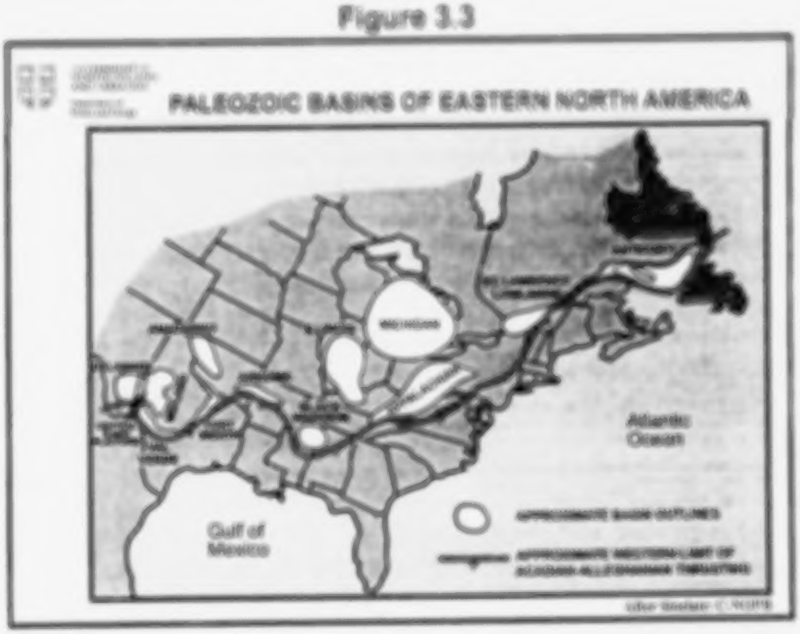

Greenland
Cartwright Fracture Zone
Scotian Shelf

Late Jurassic to Early Cretaceous - 150 to 100 MY

Modified after Kerr, 1985

Ellenburger and Arbuckle groups in the Midland, Val Verde, Anadarko, Forth Worth and Arkoma basins (figure 3.3).

Figure 3.3


PALEOZOIC BASINS OF EASTERN NORTH AMERICA
Atlantic Ocean
Gulf of Mexico
APPROXIMATE BASIN OUTLINES

Carboniferous sediments were deposited in a series of large basins that extend throughout the Maritime provinces of eastern Canada and into New England (figure 1.1). Two Carboniferous basins (the Deer Lake Basin and the Bay St. George Subbasin) are located onshore western Newfoundland. A few shallow wells drilled in these basins have yielded some significant oil and gas shows but no discoveries have yet been made in the Carboniferous rocks of Newfoundland. The Bay St. George Subbasin extends offshore into the southern Gulf of St. Lawrence where it merges with its parent Magdalen Basin (figures 1.1 and 8.1). Carboniferous sediments are also preserved within offshore basins to the south (Sydney Basin) and north of Newfoundland (St. Anthony Basin) where they are ultimately onlapped by Mesozoic strata.

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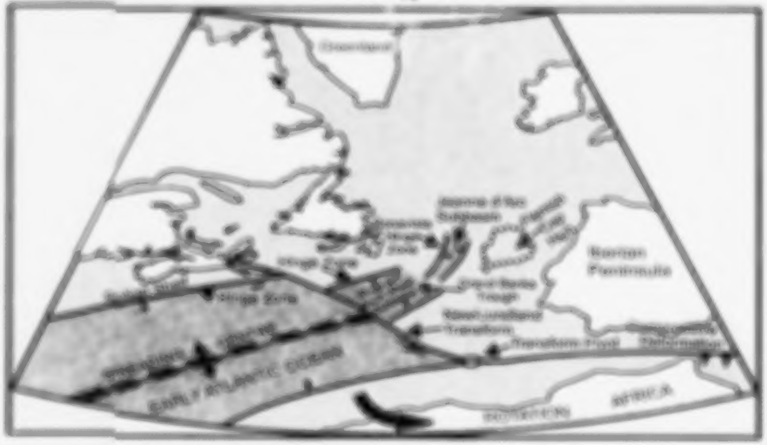
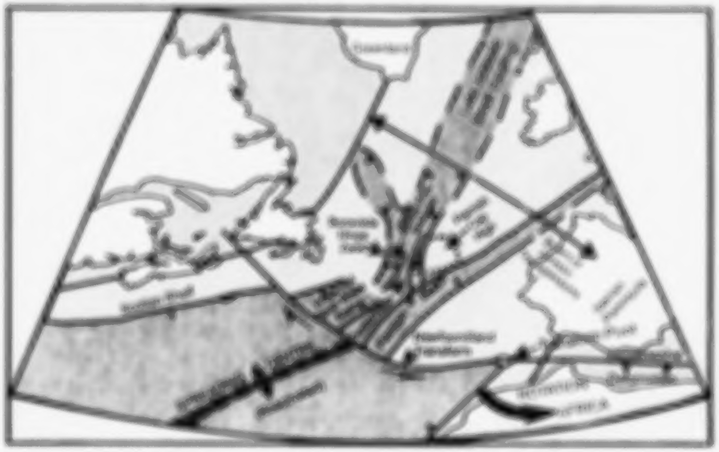
Figure 3.4

A


Greenland
Iberian Peninsula
Grand Banks Trough
Newfoundland Transform
Transform Fault
SPREADING CENTRE
EARLY ATLANTIC OCEAN
AFRICA

Late Triassic - 230 MY

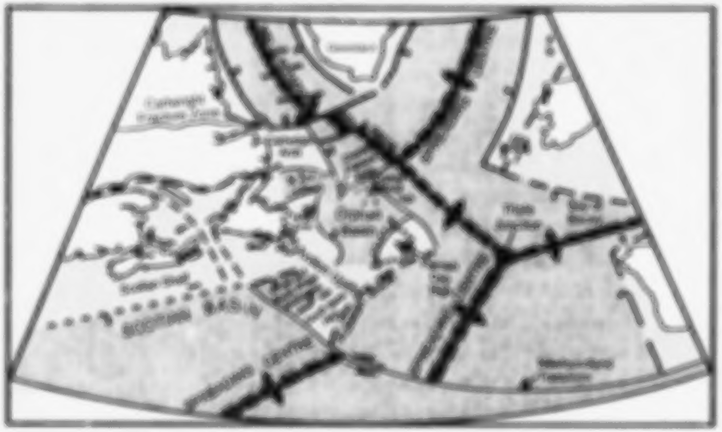
B


Greenland
SPREADING CENTRE
Newfoundland Transform
AFRICA

Mid Jurassic - 175 MY

Schematic maps depict the evolution of the eastern Canadian Mesozoic basins: In the Late Triassic the Atlantic spreading centre reached offshore Nova Scotia and created a rift valley across the Grand Banks (the Grand Banks Trough). Spreading failed to advance through the Grand Banks and eventually stepped to the east which led to the separation of the Grand Banks from Iberia. In Late Jurassic the Avalon Uplift caused the erosion of overlying and adjacent sediments and separated the basins of the NE Grand Banks from those of the SW Grand Banks. By the end of the Cretaceous the basins had fragmented into the present arrangement and had entered the passive drift phase whereby they were overlain by a thick progradational wedge of undisturbed Cenozoic sediments.

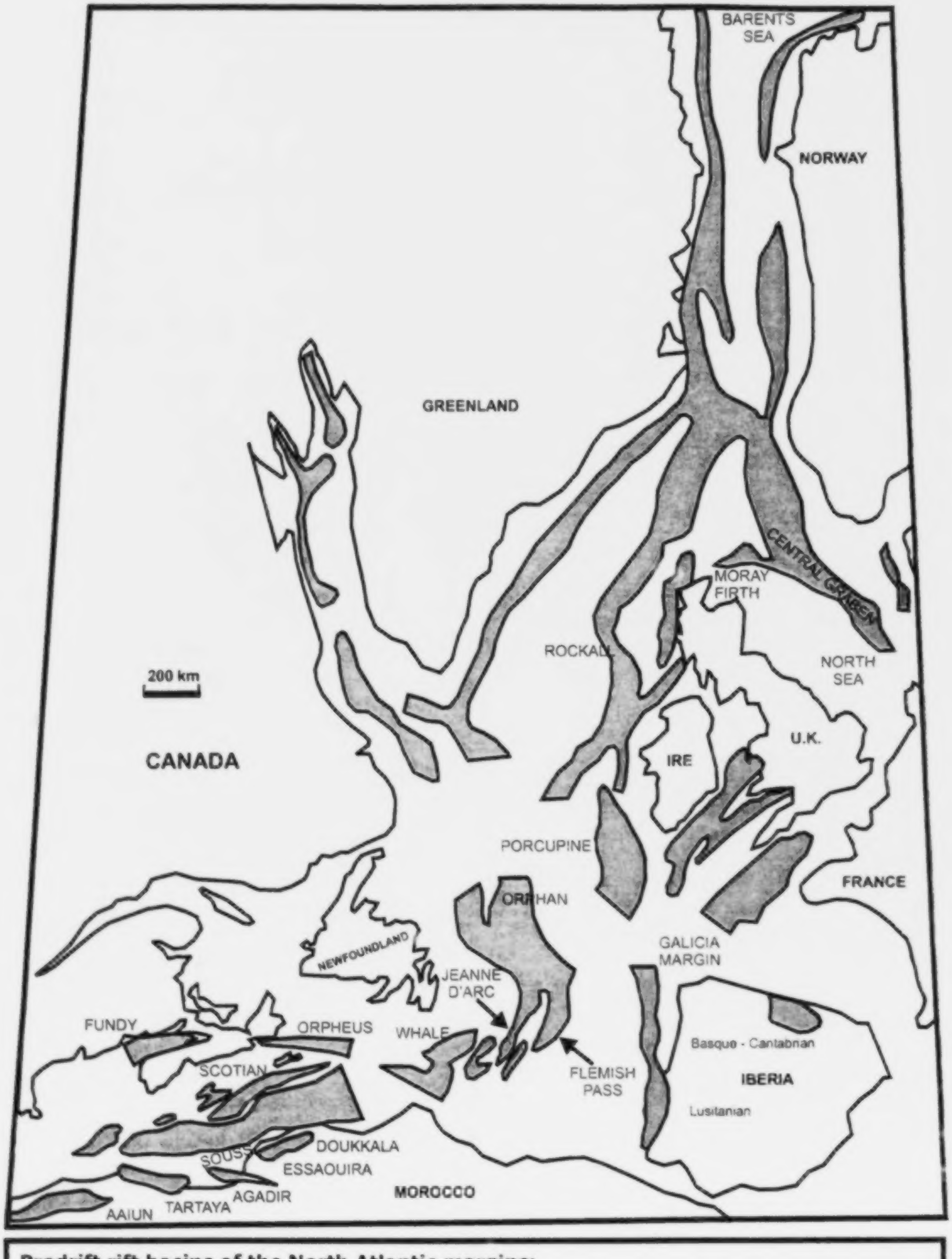
C


Greenland
SCOTIAN BASIN
SPREADING CENTRE
Newfoundland Transform

Late Jurassic to Early Cretaceous - 150 to 100 MY

Modified after Keen, 1985

Figure 3.5


BARENTS SEA
NORWAY
GREENLAND
CENTRAL GRABEN
MORAY FIRTH
ROCKALL
NORTH SEA
200 km
CANADA
IRE
U.K.
PORCUPINE
FRANCE
ORPHAN
GALICIA MARGIN
NEWFOUNDLAND
JEANNE D'ARC
FUNDY
ORPHEUS
WHALE
Basque - Cantabrian
SCOTIAN
FLEMISH PASS
IBERIA
Lusitanian
DOUKKALA
SOUSS
ESSAOUIRA
AGADIR
MOROCCO
AAIUN
TARTAYA

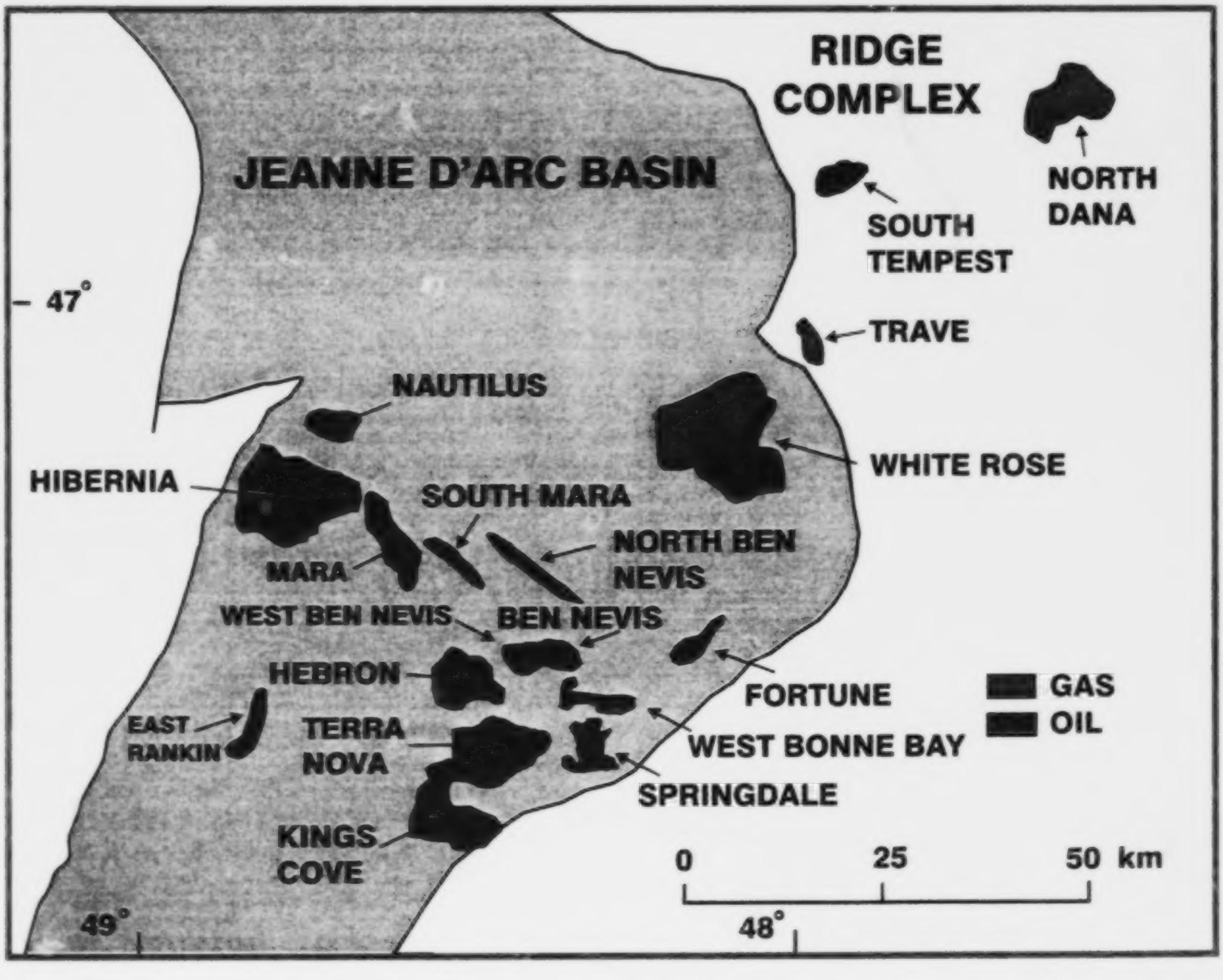
Predrift rift basins of the North Atlantic margins:
Schematic map of the early North Atlantic ocean showing the location of sedimentary basins formed by the rifting and seafloor spreading that began in the Late Triassic. After A.J. Tankard, 1989.

Section 4
Ongoing and Future Developments

This section provides a brief overview of the four largest fields in the Jeanne d'Arc basin. The Hibernia field started production in 1997; Terra Nova will begin production in 2001; and both the White Rose and Hebron/Ben Nevis are expected to be developed in the near future. The Jeanne d'Arc basin and adjacent Ridge Complex contain an additional 14 smaller discoveries, some of which will be brought to production via multi-pool developments or by subsea tie-backs to the stand alone projects.

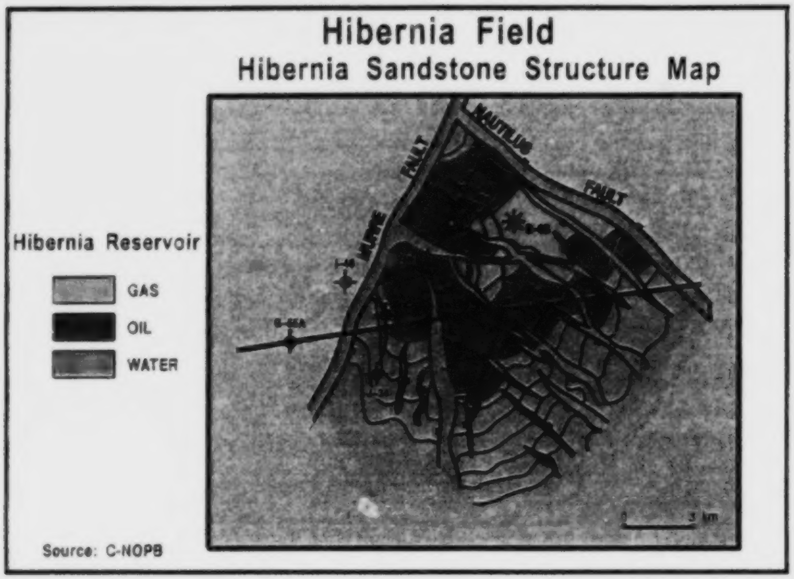
The Canada-Newfoundland Offshore Petroleum Board and Geological Survey of Canada estimate that the Jeanne d'Arc basin and Ridge Complex contain discovered resources of 2.1 billion barrels of oil, 5.05 Tcf of gas and 290 million barrels of natural gas liquids. They, estimate the undiscovered resources for this area to include 2.5 billion barrels of oil and 13.8 trillion cubic feet of natural gas.

Figure 4.1


RIDGE COMPLEX
JEANNE D'ARC BASIN
NORTH DANA
SOUTH TEMPEST
47°
TRAVE
NAUTILUS
WHITE ROSE
HIBERNIA
SOUTH MARA
NORTH BEN NEVIS
MARA
WEST BEN NEVIS
BEN NEVIS
HEBRON
FORTUNE
GAS
OIL
EAST RANKIN
TERRA NOVA
WEST BONNE BAY
SPRINGDALE
KINGS COVE
0
25
50 km
49°
48°

Schematic map of oil and gas fields in the Jeanne d'Arc Basin and Ridge Complex on the Grand Banks of Newfoundland. Modified after C-NOPB.

Hibernia Field


Hibernia Field
Hibernia Sandstone Structure Map
Hibernia Reservoir
GAS
OIL
WATER
NAUTILUS
FAULT
MURRE
FAULT
G-55A
0
3 km

Source: C-NOPB

Water Depth

- 80 metres

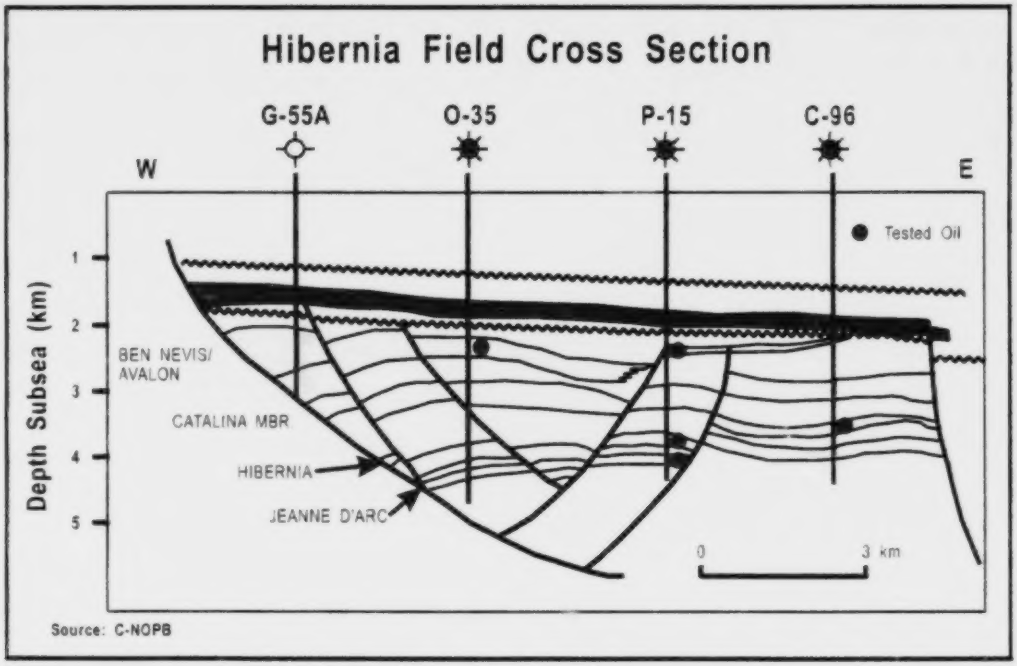
Key Reservoirs:

- Hibernia Sandstone
- Ben Nevis-Avalon Sandstone

Recoverable Reserves

- 884 million barrels oil
- 1.375 Tcf natural gas
- 145 million barrels NGL

Source: C-NOPB


Hibernia Field Cross Section
G-55A
O-35
P-15
C-96
W
E
Tested Oil
Depth Subsea (km)
1
2
3
4
5
BEN NEVIS/
AVALON
CATALINA MBR
HIBERNIA
JEANNE D'ARC
0
3 km

Source: C-NOPB

The Hibernia field is the first to be developed offshore Newfoundland and Labrador and is currently producing about 180,000 bopd from seven wells, from the Hibernia Reservoir. Development drilling of the shallower Ben Nevis-Avalon Reservoir has recently begun, and production is to begin shortly.

Figure 4.2

Terra Nova Field

Water Depth
- 93 metres

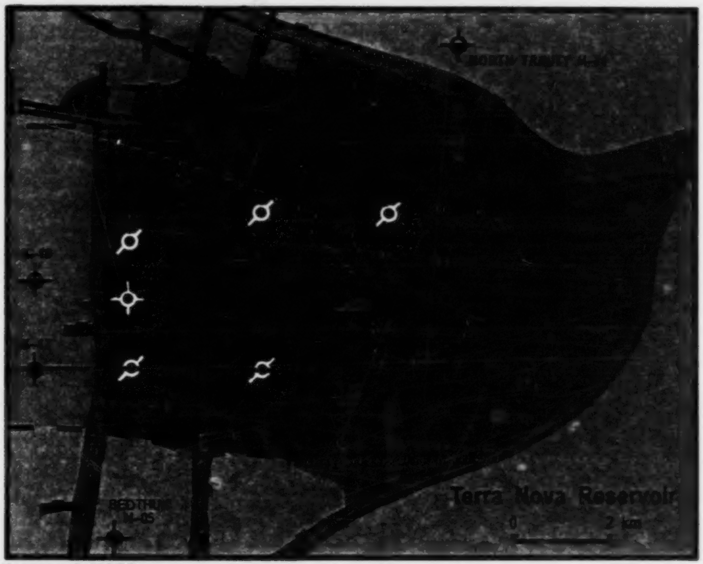
Key Reservoir:
- Jeanne d'Arc Sandstone

Recoverable Reserves
- 406 million barrels oil
- .269 Tcf natural gas
- 14 million barrels NGL

Source: C-NOPB

Terra Nova Field

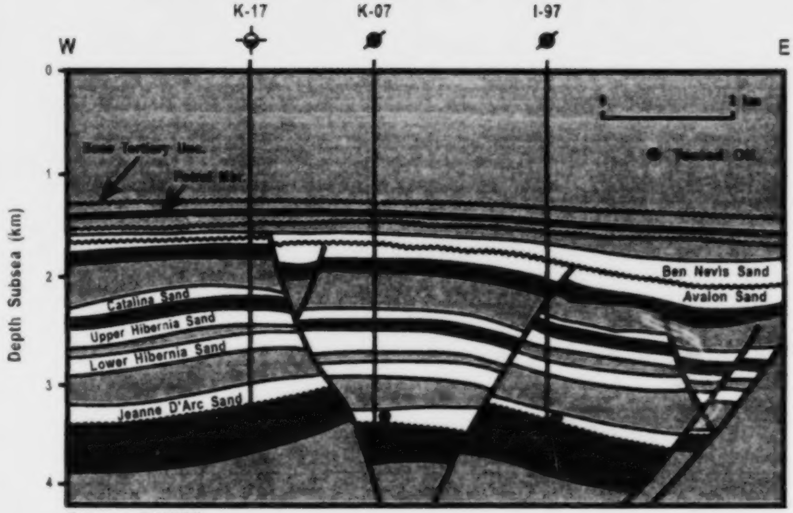
Hydrocarbon Distribution Map
in the Jeanne d'Arc Sandstone


Terra Nova Reservoir
0
2 km

Source: C-NOPB

■ Oil Zone

Terra Nova Geological Cross Section

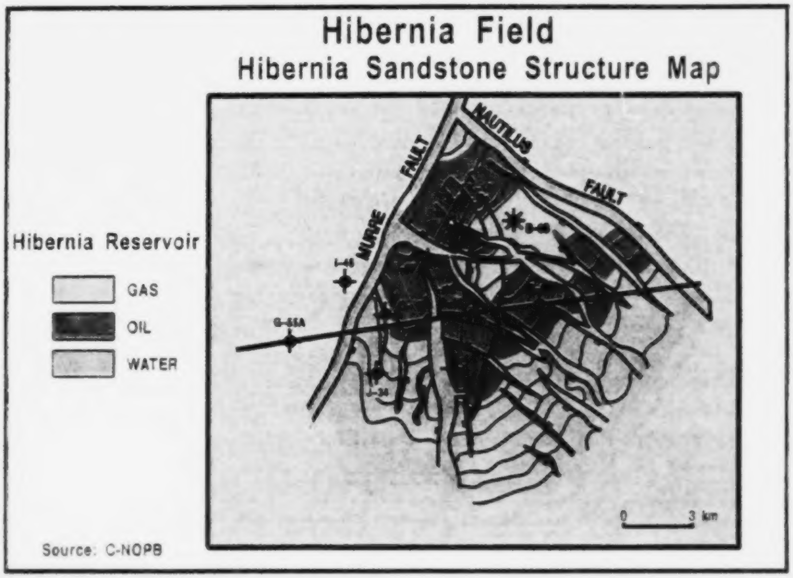

K-17
K-07
I-97
W
E
0
1
2
3
4
Depth Subsea (km)
0
2 km
Base Tertiary Unc.
Petrel Mbr.
Tested Oil
Ben Nevis Sand
Avalon Sand
Catalina Sand
Upper Hibernia Sand
Lower Hibernia Sand
Jeanne D'Arc Sand

Source: C-NOPB

Petro-Canada (the designated operator) estimates that the Terra Nova Field contains 370 million barrels in the Graben and East Flank and an additional 100 million barrels in the undrilled Far East Block. The field will be brought on production by FPSO in March 2001, and will produce at about 125,000 bopd at startup.

Figure 4.3

Hibernia Field



Hibernia Field

Hibernia Sandstone Structure Map

Hibernia Reservoir
GAS
OIL
WATER
MURRE
FAULT
NAUTILUS
FAULT
G-55A
0
3 km

Source: C-NOPB

Water Depth

- 80 metres

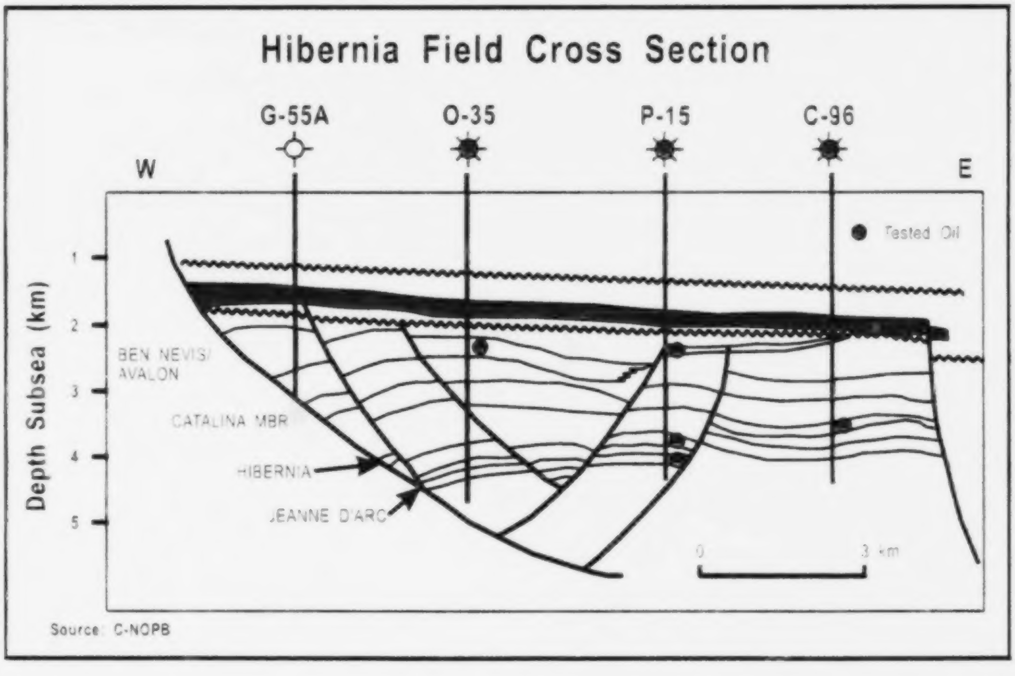
Key Reservoirs:

- Hibernia Sandstone
- Ben Nevis-Avalon Sandstone

Recoverable Reserves

- 884 million barrels oil
- 1.375 Tcf natural gas
- 145 million barrels NGL

Source: C-NOPB



Hibernia Field Cross Section

G-55A
O-35
P-15
C-96
W
E
Tested Oil
Depth Subsea (km)
1
2
3
4
5
BEN NEVIS/
AVALON
CATALINA MBR
HIBERNIA
JEANNE D'ARC
0
3 km

Source: C-NOPB

The Hibernia field is the first to be developed offshore Newfoundland and Labrador and is currently producing about 180,000 bopd from seven wells, from the Hibernia Reservoir. Development drilling of the shallower Ben Nevis-Avalon Reservoir has recently begun, and production is to begin shortly.

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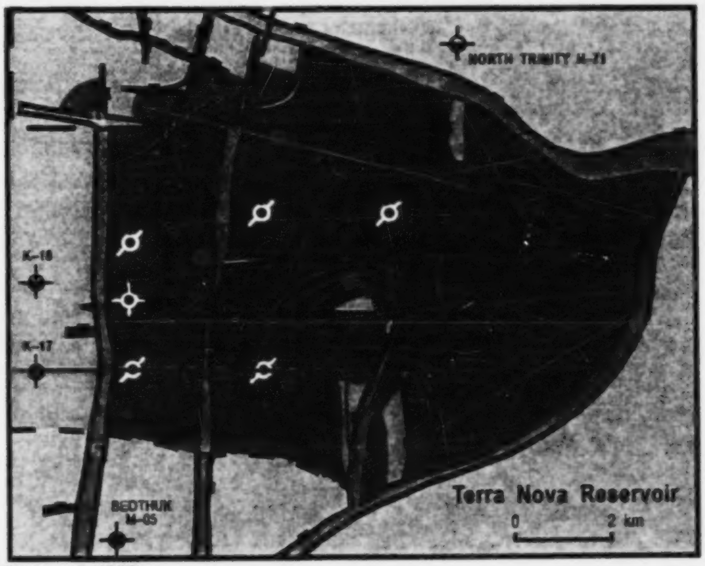
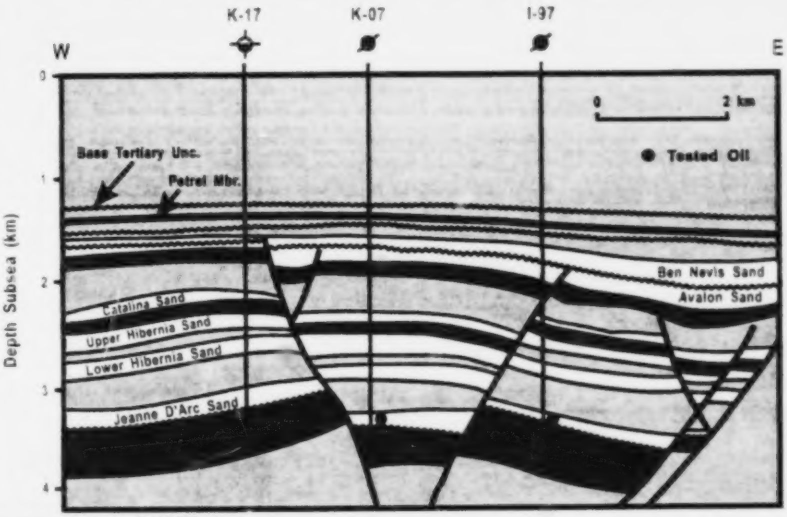
Terra Nova Field
Hydrocarbon Distribution Map in the Jeanne d'Arc Sandstone


NORTH TRINITY H-71
K-18
K-17
BEOTHUK M-05
Terra Nova Reservoir
0
2 km

Source: C-NOPB

■ Oil Zone

Terra Nova Geological Cross Section


K-17
K-07
I-97
W
E
0
1
2
3
4
Depth Subsea (km)
0
2 km
● Tested Oil
Base Tertiary Unc.
Petrel Mbr.
Ben Nevis Sand
Avalon Sand
Catalina Sand
Upper Hibernia Sand
Lower Hibernia Sand
Jeanne D'Arc Sand

Source: C-NOPB

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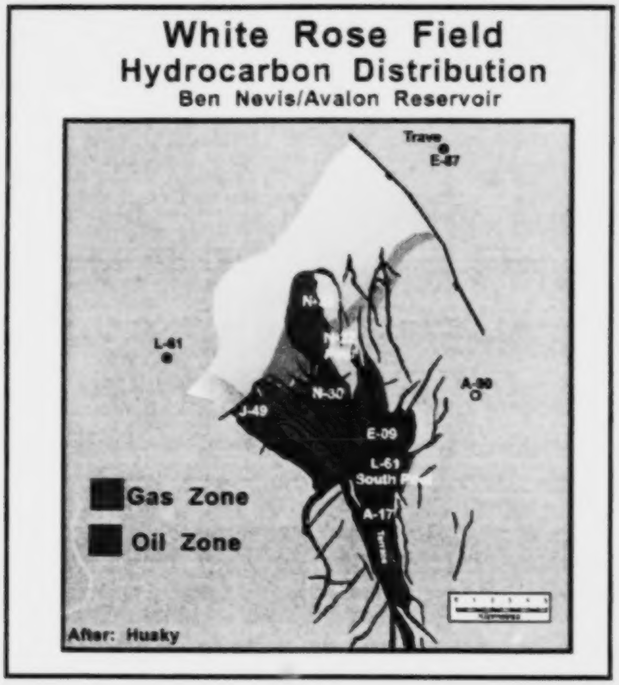
Figure 4.3

White Rose Field



White Rose Field
Hydrocarbon Distribution
Ben Nevis/Avalon Reservoir

Trave
E-87
L-61
N-30
J-49
E-09
A-90
L-61
South
A-17
Terrace
Gas Zone
Oil Zone

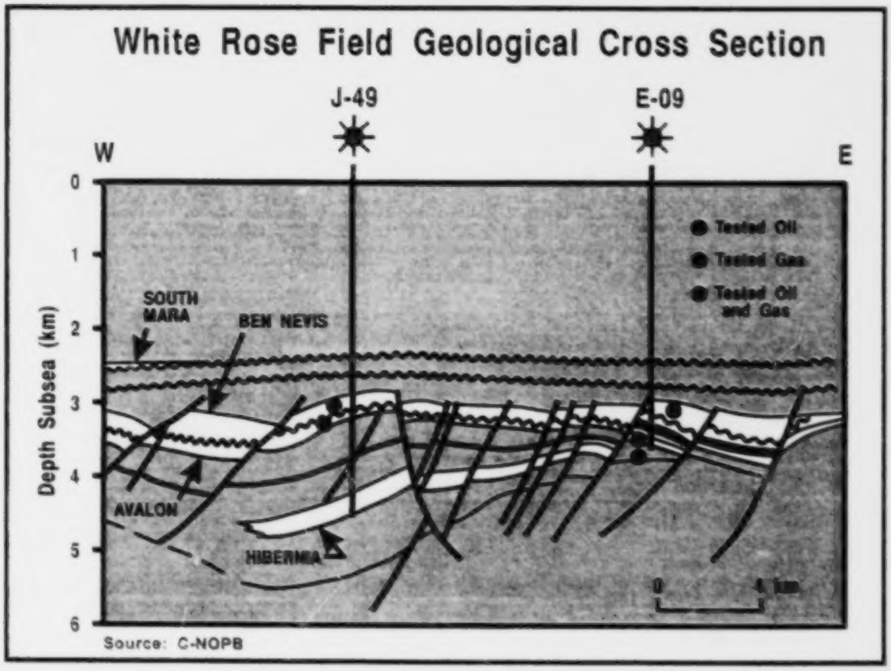
After: Husky

Water Depth
- 121 metres

Key Reservoir:
- Avalon / Ben Nevis Sandstone

Recoverable Reserves
- 275 million barrels oil
- 2.091 Tcf natural gas
- 77 million barrels NGL

Source: C-NOPB



White Rose Field Geological Cross Section

J-49
E-09
W
E
0
1
2
3
4
5
6
Depth Subsea (km)
SOUTH MARA
BEN NEVIS
AVALON
HIBERNIA
Tested Oil
Tested Gas
Tested Oil and Gas
0
4 km

Source: C-NOPB

Husky oil recently announced its intention to develop this field by FPSO. First oil is planned for late 2003 with production ranging between 75,000 and 100,000 bopd.

Figure 4.4

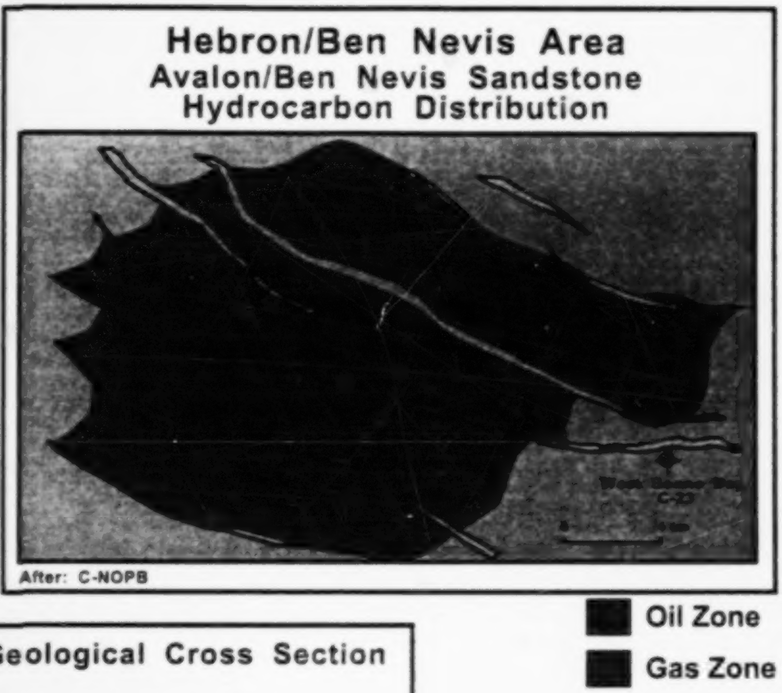
Hebron/Ben Nevis Complex

Water Depth
- 99 metres

Key Reservoirs:
- Avalon / Ben Nevis Sandstone
- Hibernia Sandstone
- Jeanne d'Arc Sandstone

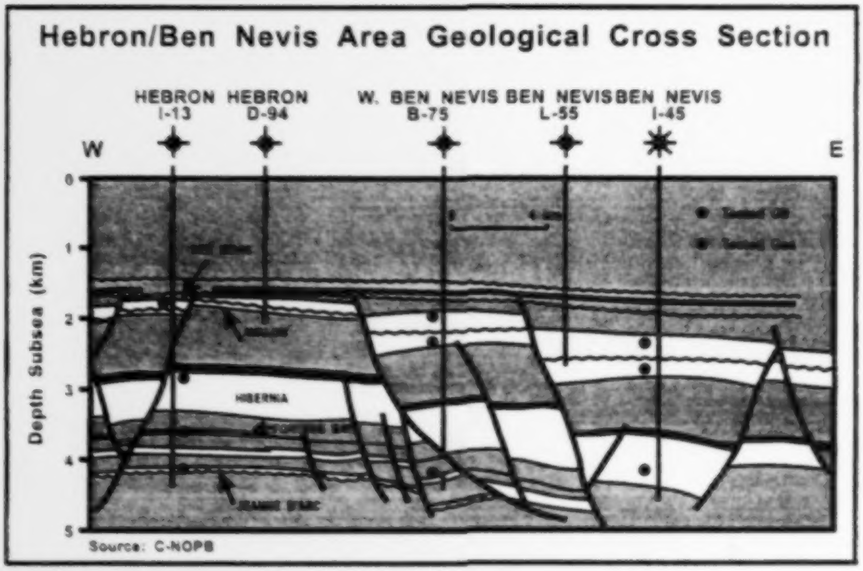
Recoverable Reserves
- 414 million barrels oil
- .313 Tcf natural gas

Source: C-NOPB


Hebron/Ben Nevis Area
Avalon/Ben Nevis Sandstone
Hydrocarbon Distribution

After: C-NOPB

■ Oil Zone
■ Gas Zone


Hebron/Ben Nevis Area Geological Cross Section

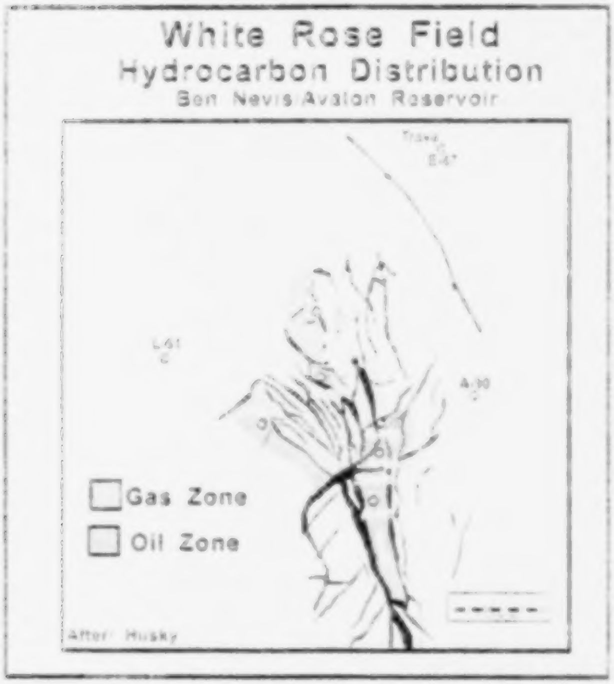
HEBRON I-13
HEBRON D-94
W. BEN NEVIS B-75
BEN NEVIS L-55
BEN NEVIS I-45
W
E
Depth Subsea (km)
0
1
2
3
4
5
HIBERNIA
JEANNE D'ARC

Source: C-NOPB

The Hebron/Ben Nevis Complex consists of three adjacent fault blocks that, although designated as separate discoveries, would likely be developed together because of their close proximity. Further delineation drilling is needed to better determine the quality and the quantity of the reserves. One challenge that will have to be addressed is that much of the oil within the Avalon/Ben Nevis Reservoir in the Hebron block is heavy (21° API). Chevron and partners are currently studying the feasibility of development. First oil production is possible by 2005.

Figure 4.5

White Rose Field

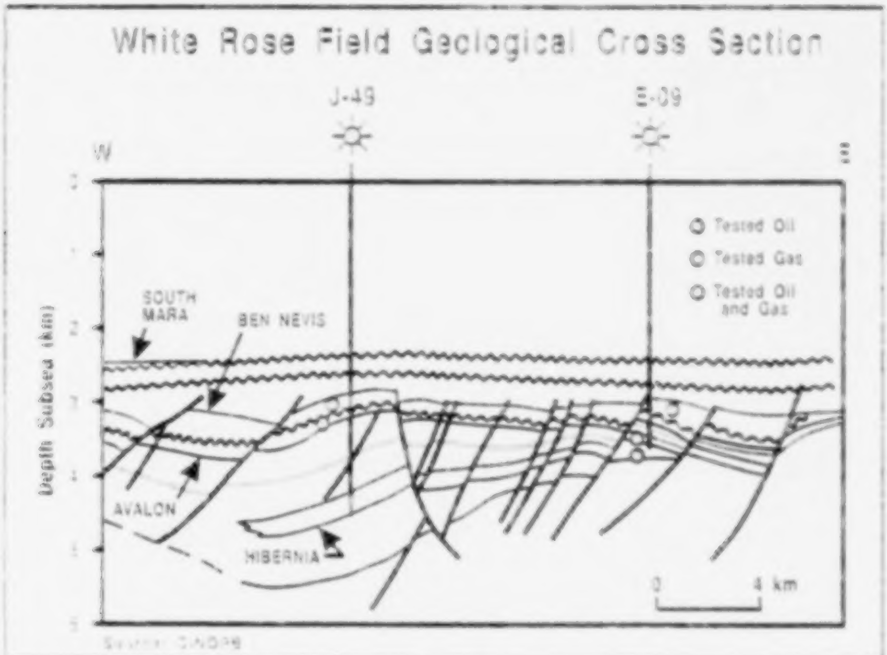

White Rose Field
Hydrocarbon Distribution
Ben Nevis/Avalon Reservoir
L-61
A-90
Gas Zone
Oil Zone
After/ Husky

Water Depth
- 121 metres

Key Reservoir:
- Avalon / Ben Nevis Sandstone

Recoverable Reserves
- 275 million barrels oil
- 2.091 Tcf natural gas
- 77 million barrels NGL

Source: C-NOPB


White Rose Field Geological Cross Section
J-49
E-09
W
E
Depth Subsea (km)
0
1
2
3
4
5
6
SOUTH MARA
BEN NEVIS
AVALON
HIBERNIA
Tested Oil
Tested Gas
Tested Oil and Gas
0
4 km
Source: C-NOPB

Husky Oil recently announced its intention to develop this field by FPSO. First oil is planned for late 2003 with production ranging between 75 000 and 100 000 bopd.

Figure 4.4

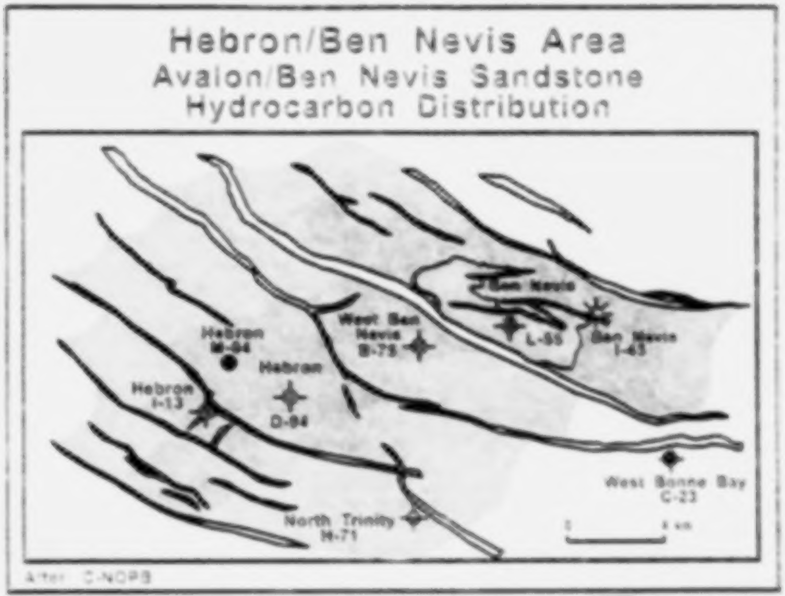
Hebron/Ben Nevis Complex

Water Depth
- 99 metres

Key Reservoirs:
- Avalon / Ben Nevis Sandstone
- Hibernia Sandstone
- Jeanne d'Arc Sandstone

Recoverable Reserves
- 414 million barrels oil
- .313 Tcf natural gas

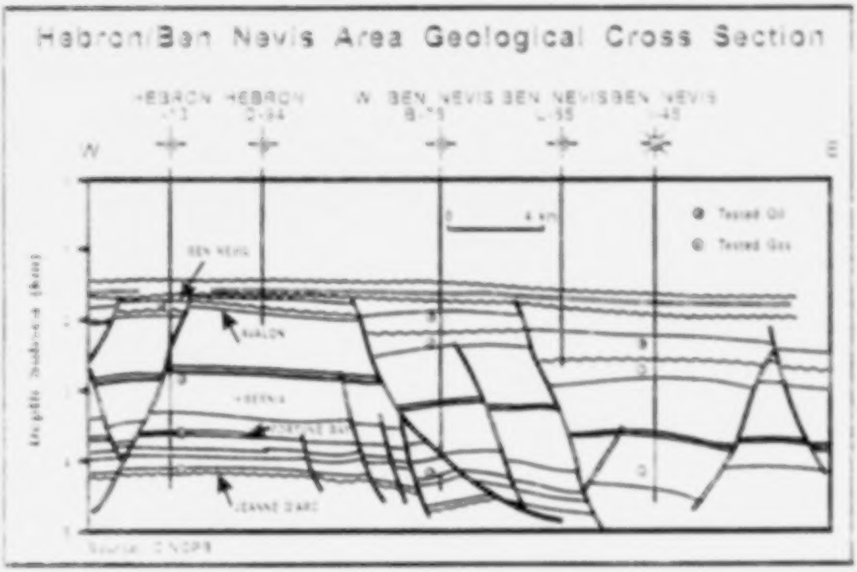
Source: C-NOPB


Hebron/Ben Nevis Area
Avalon/Ben Nevis Sandstone
Hydrocarbon Distribution

Ben Nevis
Hebron M-04
West Ben Nevis B-75
L-55
Ben Nevis I-45
Hebron
Hebron I-13
D-94
West Bonne Bay C-23
North Trinity H-71
4 km

After: C-NOPB

▨ Oil Zone
☐ Gas Zone


Hebron/Ben Nevis Area Geological Cross Section

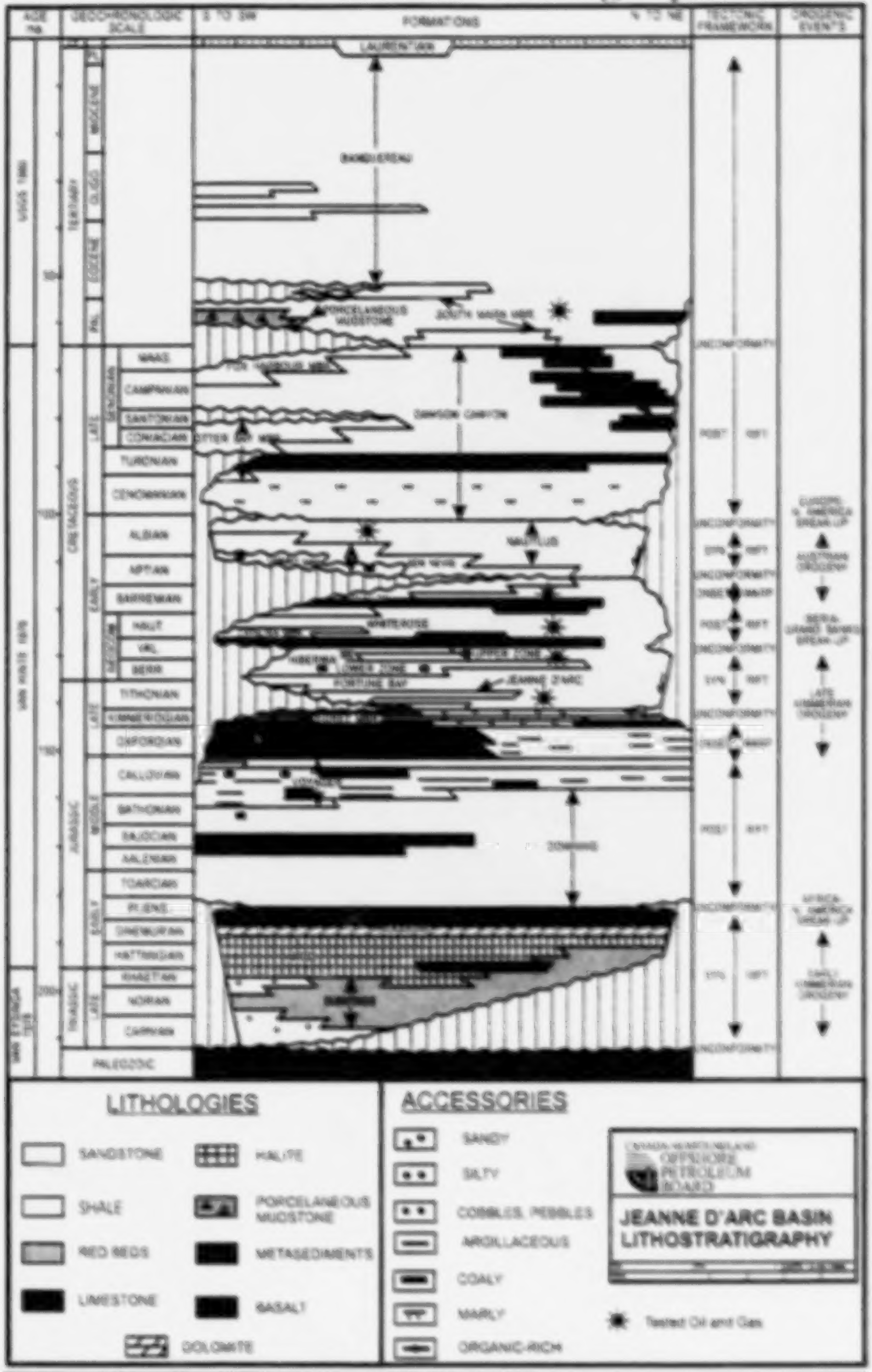
HEBRON I-13
HEBRON D-94
W. BEN NEVIS B-75
BEN NEVIS L-55
BEN NEVIS I-45
W
E
0 4 km
Tested Oil
Tested Gas
BEN NEVIS
AVALON
HIBERNIA
FORTUNE BAY
JEANNE D'ARC

Source: C-NOPB

The Hebron/Ben Nevis Complex consists of three adjacent fault blocks that, although designated as separate discoveries, would likely be developed together because of their close proximity. Further delineation drilling is needed to better determine the quality and the quantity of the reserves. One challenge that will have to be addressed is that much of the oil within the Avalon/Ben Nevis Reservoir in the Hebron block is heavy (20° API). Chevron and partners are currently studying the feasibility of development. First oil production is possible by 2005.

Figure 4.5

Northern Grand Banks Stratigraphic Chart


AGE Ma
GEOCHRONOLOGIC SCALE
S TO SW
FORMATIONS
N TO NE
TECTONIC FRAMEWORK
OROGENIC EVENTS
LAURENTIAN
BANQUEREAU
PORCELANEOUS MUDSTONE
SOUTH MARA MBR
FOX HARBOUR MBR
DAWSON CANYON
OTTER BAY MBR
NAUTILUS
BEN NEVIS
WHITEROSE
HIBERNIA
UPPER ZONE
LOWER ZONE
JEANNE D'ARC
FORTUNE BAY
DOWNING
TERTIARY
CRETACEOUS
JURASSIC
TRIASSIC
PALEOZOIC
MAAS
CAMPANIAN
SANTONIAN
CONIACIAN
TURONIAN
CENOMANIAN
ALBIAN
APTIAN
BARREMIAN
HAUT
VAL
BERR
TITHONIAN
KIMMERIDGIAN
OXFORDIAN
CALLOVIAN
BATHONIAN
BAJOCIAN
AALENIAN
TOARCIAN
PLIENS.
SINEMURIAN
HETTANGIAN
RHAETIAN
NORIAN
CARNIAN
UNCONFORMITY
POST RIFT
SYN RIFT
EUROPE-N. AMERICA BREAK-UP
AUSTRIAN OROGENY
IBERIA-GRAND BANKS BREAK-UP
LATE KIMMERIAN OROGENY
AFRICA-N. AMERICA BREAK-UP
EARLY KIMMERIAN OROGENY
LITHOLOGIES
SANDSTONE
SHALE
RED BEDS
LIMESTONE
HALITE
PORCELANEOUS MUDSTONE
METASEDIMENTS
BASALT
DOLOMITE
ACCESSORIES
SANDY
SILTY
COBBLES, PEBBLES
ARGILLACEOUS
COALY
MARLY
ORGANIC-RICH
Tested Oil and Gas
CANADA-NEWFOUNDLAND OFFSHORE PETROLEUM BOARD
JEANNE D'ARC BASIN LITHOSTRATIGRAPHY

Lithostratigraphy of the Mesozoic and Cenozoic sediments of the Grand Banks, Newfoundland. Courtesy of C-NOPB

Figure 5.1

Section 5

Northern Grand Banks

Section 5.1

Introduction

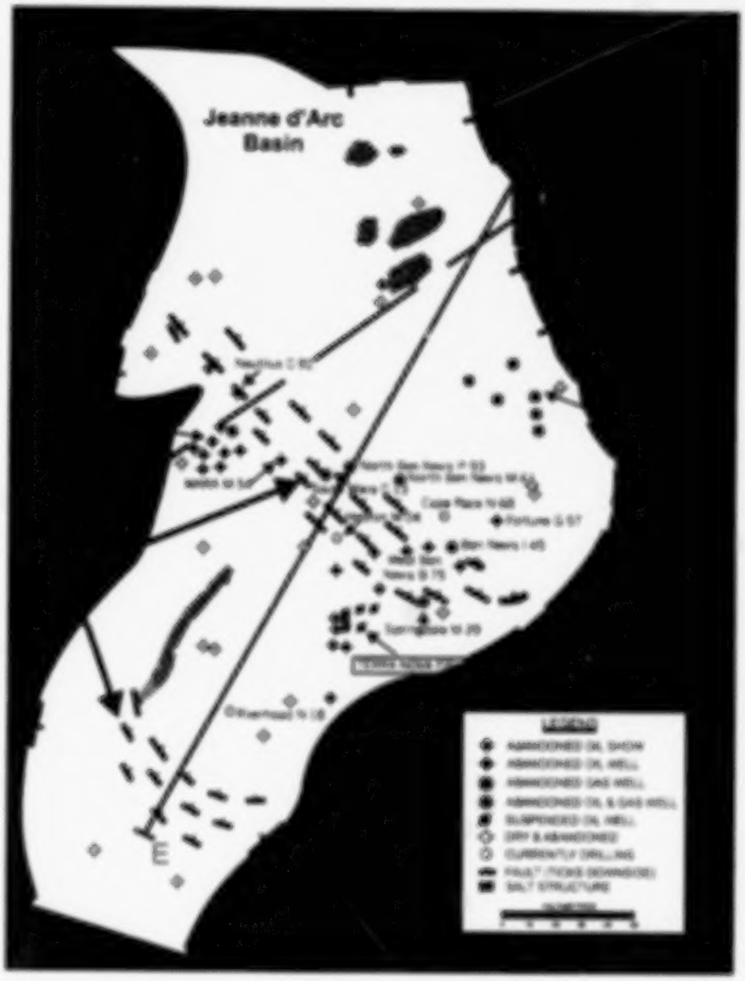
The northern Grand Banks is underlain by a collage of sedimentary basins and subbasins (including the Jeanne d'Arc, Northeast Newfoundland/Orphan, Flemish Pass basins), and intervening ridges. Sediment thicknesses range up to 20,000 metres (see figure 3.1) and are thinned or locally absent over the ridges. Although the basins have seen most of the drilling, the ridges cannot be written off as exploration targets. Three discoveries have been made on the Ridge Complex that separates the Jeanne d'Arc Basin from the Flemish Pass Basin (figure 4.2).

Section 5.2

Jeanne d'Arc Basin

The Jeanne d'Arc Basin is bounded, to the west by the Bonavista Platform, to the east by the Ridge Complex, to the south by the Avalon Uplift, and opens to the north into the East Newfoundland/Orphan basin. All of the major oil discoveries to date (including Hibernia, Terra Nova, White Rose and Hebron/Ben Nevis) are located within this basin along with eleven additional smaller discoveries. Two gas discoveries (Trave and North Dana) and one oil discovery (South Tempest) are located on the adjacent Ridge Complex.

Figure 5.2


Jeanne d'Arc Basin
Nautilus C-92
North Ben Nevis P-93
North Ben Nevis M-61
Cape Race N-68
Fortune G-57
Ben Nevis I-45
West Ben Nevis B-75
Springdale M-29
E
LEGEND
ABANDONED OIL SHOW
ABANDONED OIL WELL
ABANDONED GAS WELL
ABANDONED OIL & GAS WELL
SUSPENDED OIL WELL
DRY & ABANDONED
CURRENTLY DRILLING
FAULT (TICKS DOWNSIDE)
SALT STRUCTURE

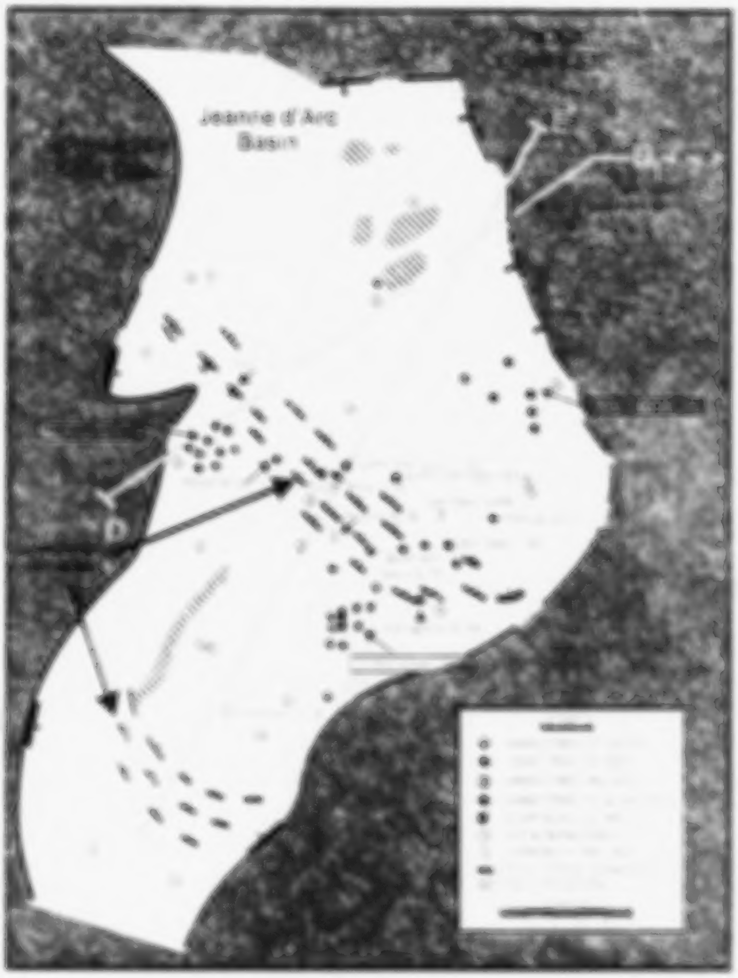
Simplified map of Jeanne d'Arc Basin illustrating the trapping significance of the trans-basin fault trend running southeast from the Hibernia Field

Figure 5.2 is a simplified map of the basin demonstrating that many of the discoveries are associated with a trans-basin fault trend running roughly southeast from Hibernia. Most discoveries were made in the early eighties after the discovery of Hibernia established the trapping significance of these faults. Figure 5.3 is a cross-section running along the axis of the basin that illustrates this fault trend, as well as other trapping mechanisms. Although almost all of the drilling in offshore Newfoundland and Labrador has been focused on structural traps, the *Mara M-54* discovery, which flow-tested 620 barrels of oil per day from a Lower Tertiary submarine fan (South Mara Sandstones), demonstrates the potential for successful stratigraphic plays.

The most important reservoirs thus far are the Lower Cretaceous Avalon/Ben Nevis sandstones, the Hibernia sandstones and the Upper Jurassic Jeanne d'Arc sandstones. The Hibernia Sandstone

Section 5 Northern Grand Banks

Figure 5.2



Simplified map of Jeanne d'Arc Basin illustrating the tectonic significance of the trans-basin fault trend running southeast from the Hibernia Field.

Introduction

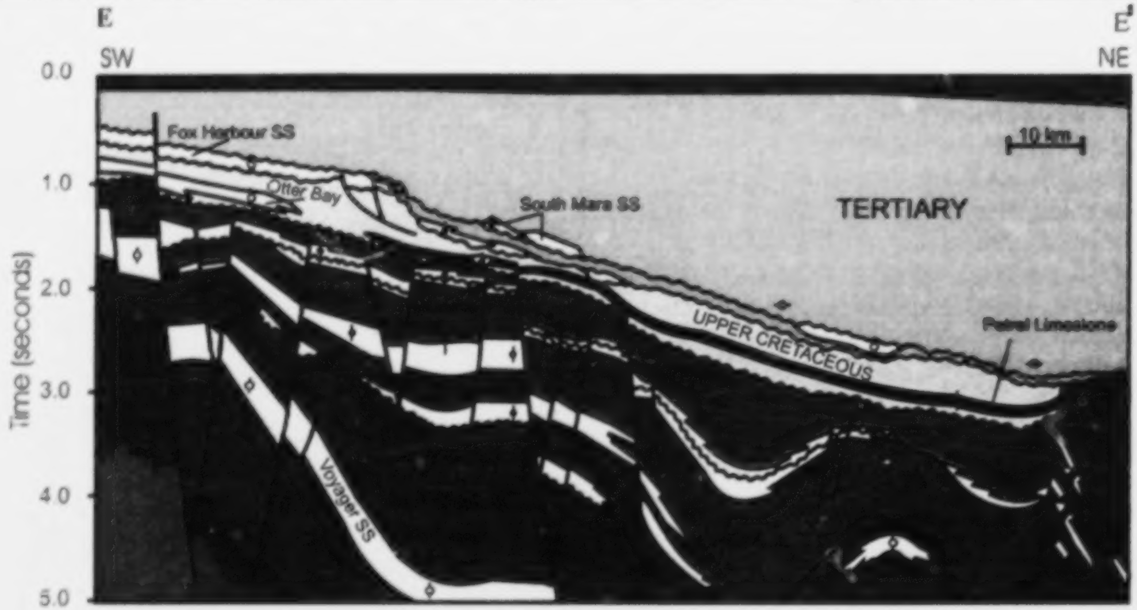
The northern Grand Banks is underlain by a collage of sedimentary basins and subbasins including the Jeanne d'Arc, Northeast Newfoundland and Orphan, Flemish Pass basins, and intervening ridges. Sediment thicknesses range up to [illegible] metres (see figure [illegible]) and the [illegible] is locally absent on the ridges. Although the basins have seen most of the drilling, the ridges cannot be written off as exploration targets. Three discoveries have been made on the Ridge Complex that separates the Jeanne d'Arc Basin from the Flemish Pass Basin (figure 4.2).

Jeanne d'Arc Basin

The Jeanne d'Arc Basin is bounded to the west by the Bonavista Platform, to the east by the Ridge Complex, to the south by the Avalon Uplift, and opens to the north into the East Newfoundland Orphan Basin. All of the significant discoveries to date, including Hibernia, Terra Nova, White Rose and Hebron/Ben Nevis, are located within this basin [illegible] [illegible] [illegible] [illegible] [illegible] on the adjacent Ridge Complex. Figure 5.2 is a simplified map of the [illegible] with a trans-basin fault trend running roughly southeast from Hibernia. [illegible] Hibernia [illegible] the tectonic significance of these faults. Figure 5.[illegible] is a cross-section [illegible] [illegible]

The [illegible] Hibernia [illegible] and the Upper Jurassic Jeanne d'Arc sandstones. The Hibernia sandstone [illegible]

Figure 5.3



Simplified schematic cross section based on seismic line 6313.85 (after Sinclair, 1994)

A cross section along the axis of the Jeanne d'Arc Basin that illustrates the presence of stacked sandstone reservoirs throughout the basin and the principal trapping mechanism associated with normal faults that trend SE across the basin. See figure 4.2 for section location.

reservoir (at the Hibernia field), is currently the only reservoir with a production history and has demonstrated an exceptional productive capacity. The Hibernia field is currently producing approximately 180,000 bopd from seven wells. The permeability of the Hibernia Sandstone has been measured as high as 26.9 darcies, and as having porosity as high as 21% (19.3% median).[1]

The oils within the basin are sweet with typical API indices in the thirties. One notable exception is the Avalon/Ben Nevis reservoir within the Hebron field, which contains sweet but heavier oil of 21° API. This oil is believed to have either been biodegraded or water-washed because of adjacency to a fault (Sinclair et al, 1992).

The primary source rock in the Jeanne d'Arc Basin is recognized as the, Kimmeridgian, Egret Member. Other potential source rocks have been identified in the Voyager and Jeanne d'Arc formations but are believed to be of limited hydrocarbon generative capacity and restricted areal extent (Sinclair et al, 1992). Organic rich shales identified in the Lower Tertiary at *Nautilus C-92* are immature and incapable of generating petroleum because of syndepositional oxidation (Sinclair, 1988). As *Nautilus C-92* is located at the western margin of the basin it is possible that these organic shales could exist in an anoxic state in deeper parts of the basin and may also move into the oil window as the Tertiary section thickens to the north.

---

[1] Permeabilities to air in laboratory. Source HMDC, unpublished data.

Jeanne d'Arc and Ridge Complex

Exploration Wells	52
Significant Discoveries	18

Source Rock: Egret Member (Kimmeridgian)
Potential Source: Organic rich Tertiary Section

Reservoirs:

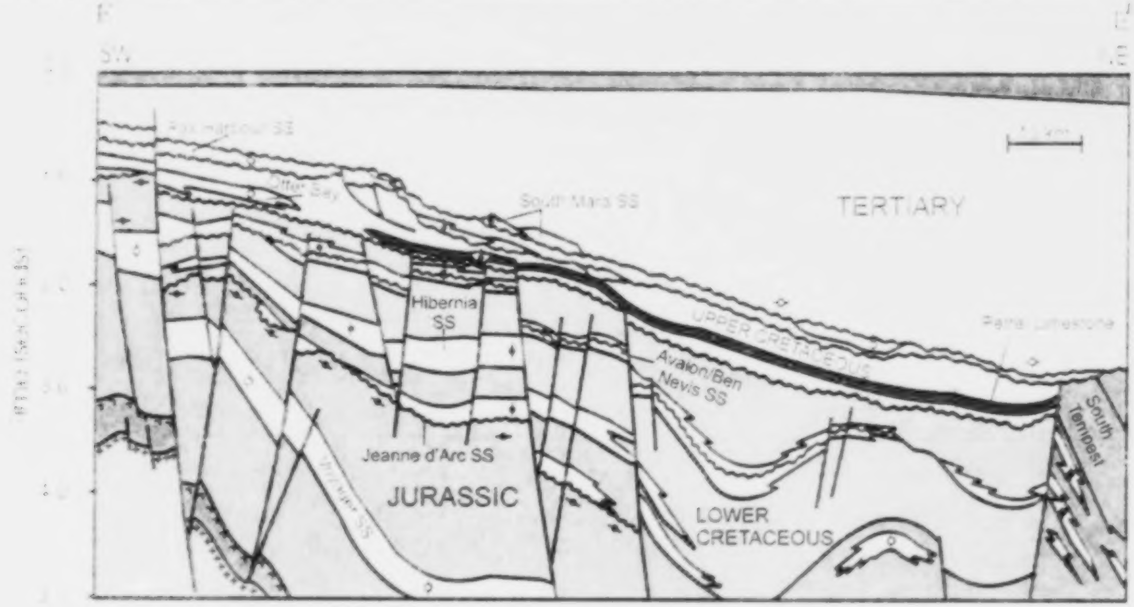
- South Mara Sandstones
- Ben Nevis Sandstones
- Avalon Sandstones
- Catalina Sandstones
- Hibernia Sandstones
- Jeanne d'Arc Sandstones
- South Tempest Sandstones

Play Types:

- Rollover anticlines (Hibernia Field)
- Horst block fault features (Mara Structure or Ridge Complex)
- Tilted fault blocks (Ben Nevis, West Ben Nevis, Hebron)
- Stratigraphic pinchouts in the Jeanne d'Arc sand (Terra Nova Field)
- Drape over deep salt swells (White Rose) and other deep features
- Drape over and pinchouts against salt diapirs (Adolphus)
- Prograding sand wedges; channel sands; fans & turbidites (South Mara)

Table 5.1

Figure 5.3


E
SW
NE
Fox Harbour SS
Otter Bay
South Mara SS
TERTIARY
Hibernia SS
UPPER CRETACEOUS
Petrel Limestone
Avalon/Ben Nevis SS
South Tempest
Jeanne d'Arc SS
JURASSIC
Voyager SS
LOWER CRETACEOUS

Simplified schematic cross section based on seismic line [illegible] (after Sinclair 1988)

A cross section along the axis of the Jeanne d'Arc Basin that illustrates the presence of stacked sandstone reservoirs throughout the basin and the principal trapping mechanism associated with normal faults that trend SE across the basin. See figure 4.2 for section location.

reservoir in the Hibernia field, is currently the only reservoir with a production history and has demonstrated an exceptional productive capacity. The Hibernia field is currently producing approximately [illegible] (bopd) from seven wells. The permeability of the Hibernia sandstone has been measured as high as 2-5 darcies, and as having porosity as high as [illegible] database).

The oils within the basin are sweet with typical API indices in the thirties. One notable exception is the Avalon/Ben Nevis reservoir within the Hibernia field, which contains sweet but heavy oil of 21° API. The oil is believed to have either been biodegraded or water washed because it is adjacent to a fault (Sinclair et al., 1992).

The principal source rock in the Jeanne d'Arc Basin is recognized as the Kimmeridgian Egret Member. Other potential source rocks have been identified in the Voyager and Jeanne d'Arc formations but are believed to be of limited hydrocarbon generative capacity and restricted areal extent (Sinclair et al., 1992). Organic rich zones identified in the Lower Tertiary at [illegible] are immature and incapable of generating petroleum because of insufficient burial [illegible]. As [illegible] history of the basin it is possible that these organic rich zones could exist in an [illegible] deeper parts of the basin and may also [illegible] in the Tertiary section [illegible].

Jeanne d'Arc and Ridge Complex

Exploration Wells	52
Significant Discoveries	18

Source Rock: Egret Member (Kimmeridgian)
Potential Source: Organic rich Tertiary Section

Reservoirs:
- South Mara Sandstones
- Ben Nevis Sandstones
- Avalon Sandstones
- Catalina Sandstones
- Hibernia Sandstones
- Jeanne d'Arc Sandstones
- South Tempest Sandstones

Play Types:
- Rollover anticlines (Hibernia Field)
- Horst block fault features (Mara Structure or Ridge Complex)
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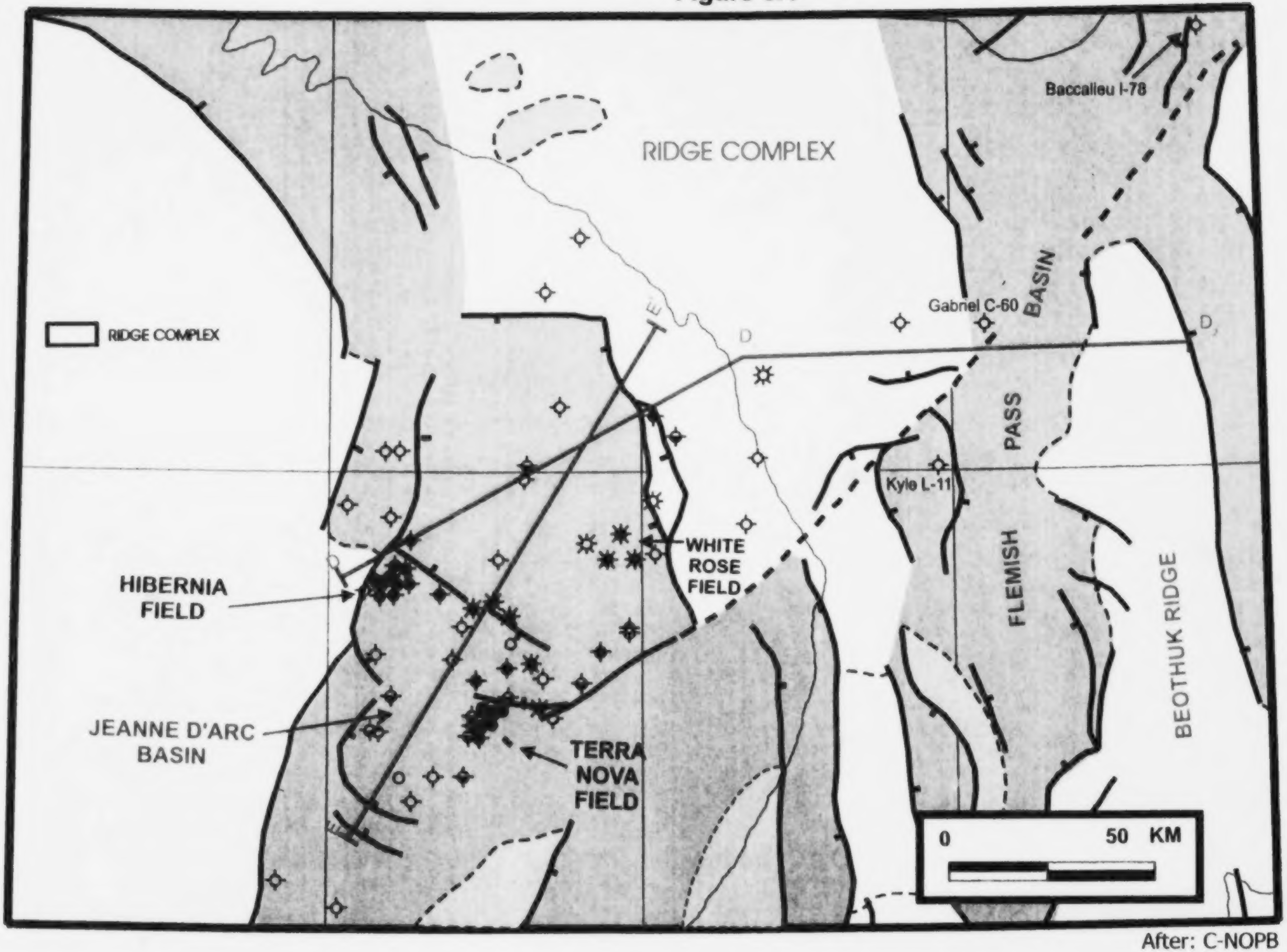
- Drape over deep salt swells (White Rose) and other deep features
- Drape over and pinchouts against salt diapirs (Adolphus)
- Prograding sand wedges; channel sands; fans & turbidites (South Mara)

Table 5.1

Figure 5.4


RIDGE COMPLEX
RIDGE COMPLEX
Baccalieu I-78
Gabriel C-60
BASIN
PASS
FLEMISH
Kyle L-11
BEOTHUK RIDGE
D
D,
E
WHITE ROSE FIELD
HIBERNIA FIELD
JEANNE D'ARC BASIN
TERRA NOVA FIELD
0
50 KM

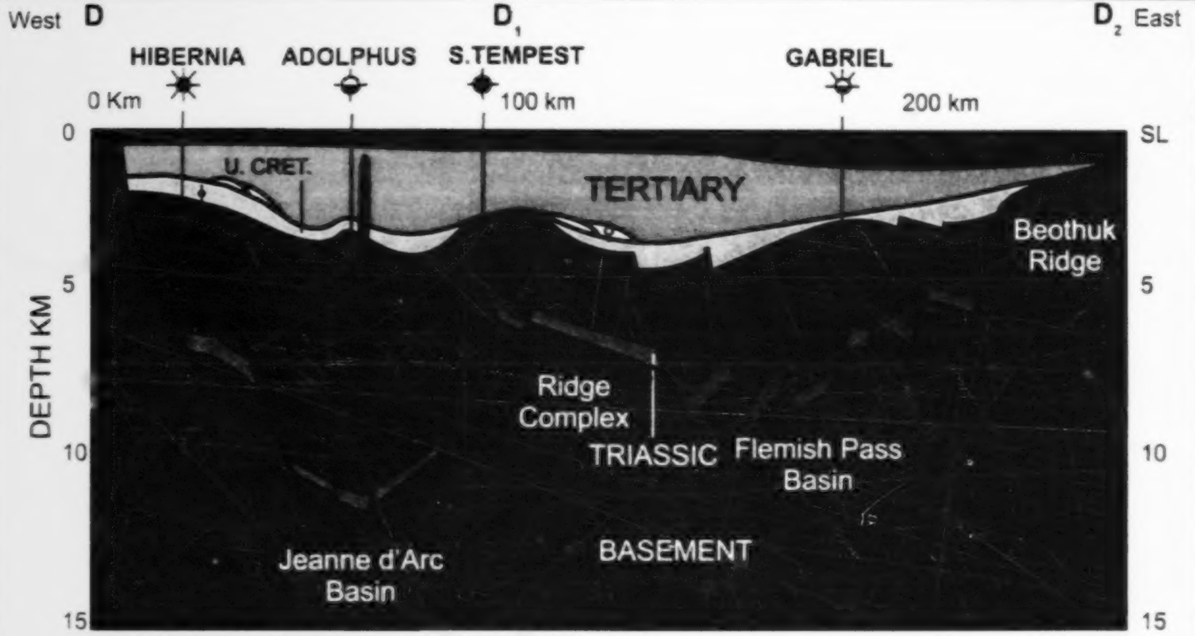
After: C-NOPB

This basin outline map shows the location of the Flemish Pass Basin with respect to the Ridge Complex and Jeanne d'Arc Basin and identifies the three wells drilled in the Flemish Pass Basin so far.

Flemish Pass Basin

The Flemish Pass Basin (figure 5.4) has only three wells drilled to date - *Kyle L-11*, *Baccalieu I-78*, and *Gabriel C-60*. These wells have proven the existence of both reservoir and source rocks. *Gabriel C-60* is listed as having an oil show (a sandstone core of equivalent age to the Hibernia Formation bled oil), and gas shows while drilling. Most of the basin is in water depths of about 1000 metres. Recent landsale parcels in this basin have attracted record bids and extensive 3D seismic has been acquired over the past couple of years. Petro-Canada has indicated that it has identified five targets in this basin, each having reserve potential in the 500 million barrel range.

Figure 5.5


West
D
D1
D2
East
HIBERNIA
ADOLPHUS
S.TEMPEST
GABRIEL
0 Km
100 km
200 km
0
5
10
15
SL
DEPTH KM
U. CRET.
TERTIARY
Beothuk Ridge
Ridge Complex
TRIASSIC
Flemish Pass Basin
Jeanne d'Arc Basin
BASEMENT

Source: Faught (1986) Shell Canada / Ziegler (1986)

This cross section illustrates the similarities between the Jeanne d'Arc and Flemish Pass Basins, which were connected until the uplift of the Ridge Complex during the Early Cretaceous. Drilling has confirmed the presence of equivalent-age source and reservoir rocks in the Flemish Pass Basin as have been found in the Jeanne d'Arc Basin. See figure 5.4 for section location.

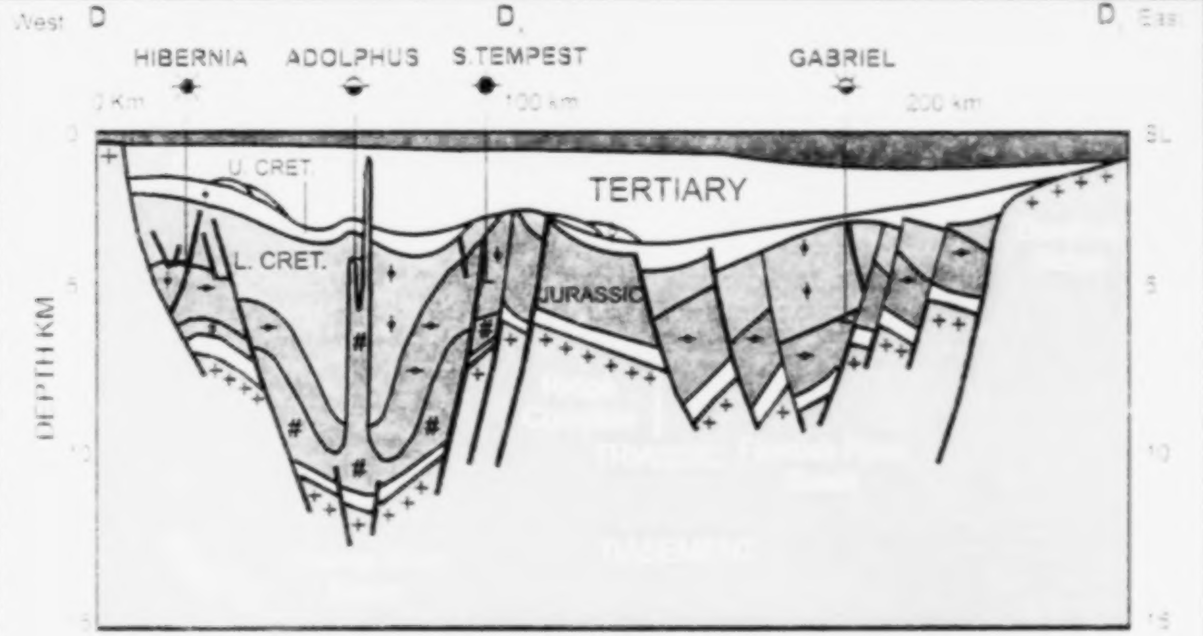
Flemish Pass Basin Exploration Wells 3 Oil and Gas Shows 1 (Gabriel C-60)	**Play Types:** • Tilted fault blocks • Rollover anticlines • Stratigraphic pinchout of Jeanne d'Arc sands against Tithonian unconformity • Stratigraphic pinchout of Avalon sands against mid-Cretaceous unconformity • Prograding sand wedges, channel sands, fans and turbidites in the lower Tertiary.
Source Rock: Egret Member **Reservoirs:** Hibernia and Jeanne d'Arc Sandstone equivalents have been encountered. Other reservoirs similar to Jeanne d'Arc Basin expected.	

Table 5.2

Flemish Pass Basin

The Flemish Pass Basin (figure 5.4) has only three wells drilled to date (*Kyle L-11, Baccalieu I-78* and *Gabriel C-60*). These wells have proven the existence of both reservoir and source rocks. *Gabriel C-60* is listed as having an oil show (a sandstone core of equivalent age to the Hibernia Formation bled oil) and gas shows while drilling. Most of the basin is in water depths of about 1000 metres. Recent landsale parcels in this basin have attracted record bids and extensive 3D seismic has been acquired over the past couple of years. Petro-Canada has indicated that it has identified five targets in this basin, each having reserve potential in the 500 million barrel range.

Figure 5.5



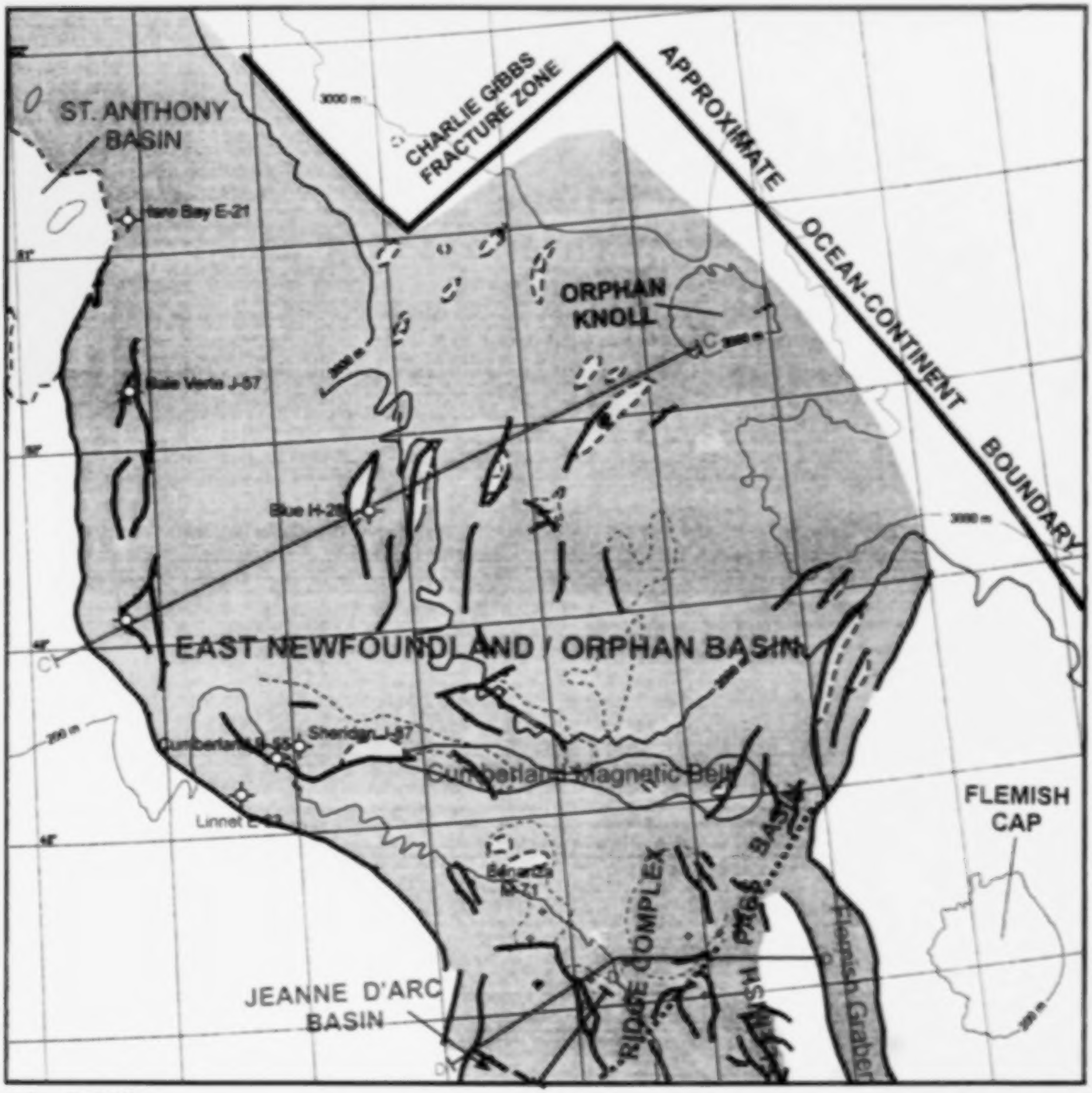
Source: Faught (1986), Shell Canada - Ziegler (1986)

This cross section illustrates the similarities between the Jeanne d'Arc and Flemish Pass Basins, which were connected until the uplift of the Ridge Complex during the Early Cretaceous. Drilling has confirmed the presence of equivalent-age source and reservoir rocks in the Flemish Pass Basin as have been found in the Jeanne d'Arc Basin. See figure 5.4 for section location.

Flemish Pass Basin Exploration Wells 3 Oil and Gas Shows 1 (Gabriel C-60)	**Play Types:** • Tilted fault blocks • Rollover anticlines • Stratigraphic pinchout of Jeanne d'Arc sands against Tithonian unconformity • Stratigraphic pinchout of Avalon sands against mid-Cretaceous unconformity • Prograding sand wedges, channel sands, fans and turbidites in the lower Tertiary.
Source Rock: Egret Member **Reservoirs:** Hibernia and Jeanne d'Arc Sandstone equivalents have been encountered. Other reservoirs similar to Jeanne d'Arc Basin expected.	

Table 5.2

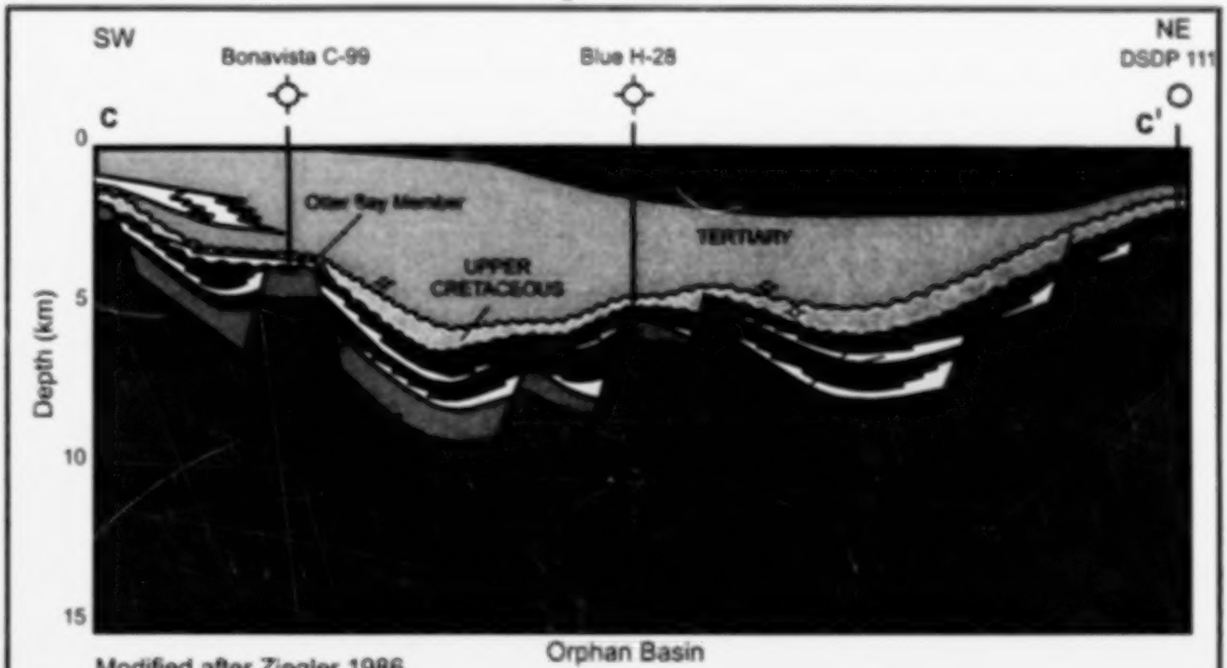
East Newfoundland/Orphan Basin


ST. ANTHONY BASIN
CHARLIE GIBBS FRACTURE ZONE
APPROXIMATE OCEAN-CONTINENT BOUNDARY
3000 m
Hare Bay E-21
ORPHAN KNOLL
C
Baie Verte J-57
Blue H-28
C'
EAST NEWFOUNDLAND / ORPHAN BASIN
200 m
Cumberland B-55
Sheridan J-87
Cumberland Magnetic Belt
Linnet E-63
FLEMISH CAP
Bonanza M-71
RIDGE COMPLEX
FLEMISH PASS BASIN
Flemish Graben
JEANNE D'ARC BASIN
D

After C-NOPB

Figure 5.6

Figure 5.7



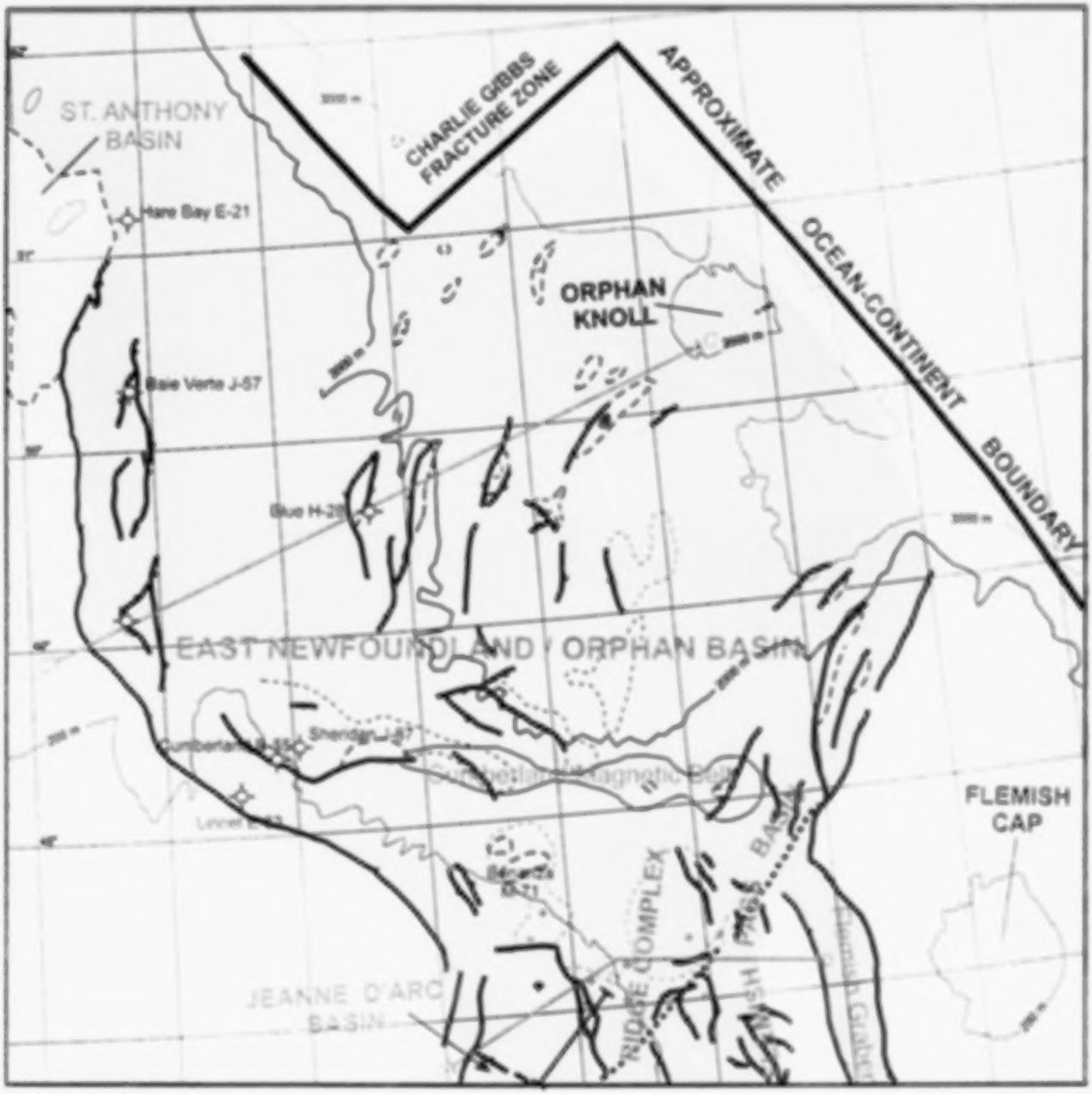
Modified after Ziegler 1986

Orphan Basin Cross-Section: Although no Jurassic section was intersected in the petroleum exploration wells it was encountered in the Deep Sea Drilling Program hole #111 on the Orphan Knoll (Ziegler, 1986).

The East Newfoundland/Orphan Basin (hereinafter referred to as the Orphan Basin) is bounded to the west by the Bonavista Platform, to the east by the ocean continent boundary, to the north by the Charlie Gibbs Fracture Zone and to the south by the Cumberland Magnetic Belt. This encompasses an area of about 150,000 km^2 with Mesozoic and Cenozoic sediments reaching thickness exceeding ten kilometres. Although the basin contains a number of very large structures only seven wells have been drilled to date. Most of the eastern side of the basin lies in deeper water (greater than 2000 metres). A series of en-echelon ridge-like structures dominate the centre of the basin, one of which was drilled at *Blue H-28*. The *Bonavista C-99* and *Cumberland B-55* wells were drilled on a high terrace on the west side of the basin intersected a shallow-marine, Upper Cretaceous section overlaying Carboniferous sediments. The *Linnet E-63* well was drilled slightly off the crest of a similar structure, and encountered a shaly Lower Cretaceous section with interbedded sandstones. Seismic data indicate a thick succession of Mesozoic was preserved between the ridges, so it is likely that a full section of Lower Cretaceous and Jurassic exists within the deeper parts basin. The presence of Jurassic is supported by the results of Deep Sea Drilling Program hole #111 that bottomed in Jurassic sediments on the west flank of the Orphan Knoll.

Minor gas shows were encountered in the *Blue H-28* and *Cumberland B-55* wells, but with so little of the section drilled it is not surprising that a source rock has yet to be identified. Based on depth

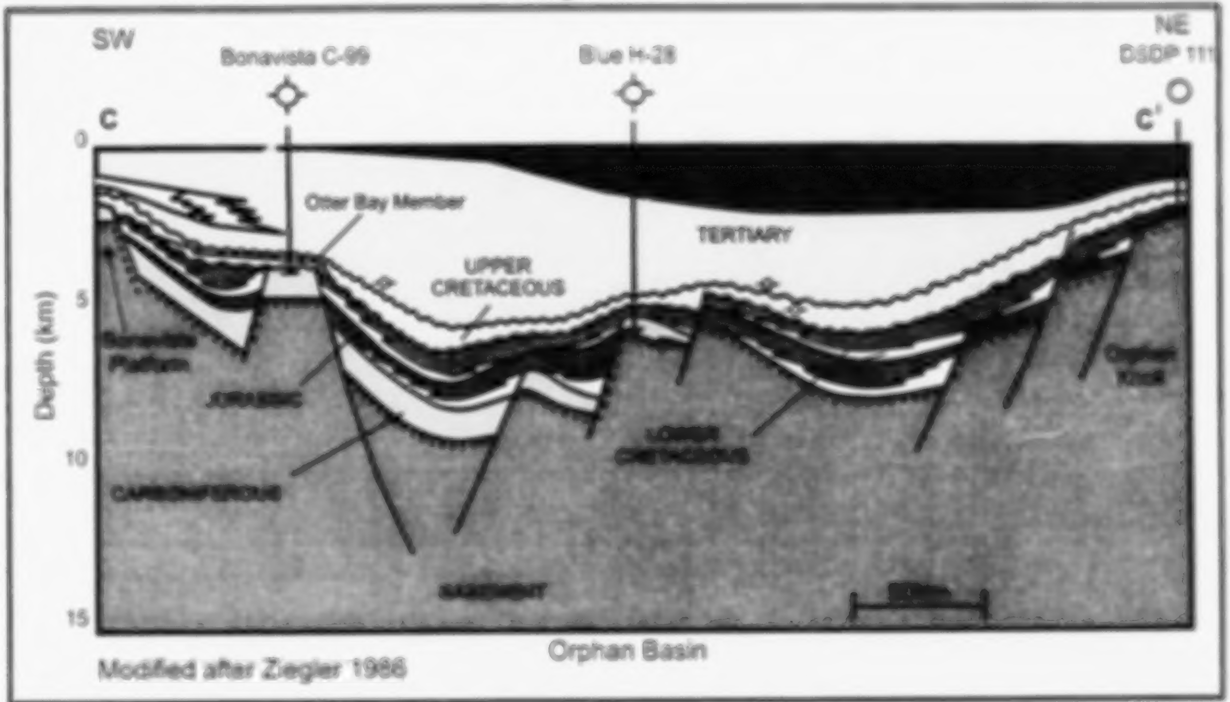
East Newfoundland/Orphan Basin


ST. ANTHONY
BASIN
Hare Bay E-21
Baie Verte J-57
Blue H-28
CHARLIE GIBBS
FRACTURE ZONE
APPROXIMATE
OCEAN-CONTINENT
BOUNDARY
ORPHAN
KNOLL
2000 m
EAST NEWFOUNDLAND / ORPHAN BASIN
Cumberland B-55
Sheridan J-87
Cumberland Magnetic Belt
Linnet E-63
Bonanza M-71
JEANNE D'ARC
BASIN
RIDGE COMPLEX
FLEMISH PASS BASIN
Flemish Graben
FLEMISH
CAP
200 m

After C-NOPB

Figure 5.6

Figure 5.7



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Minor gas shows were encountered in the *Blue H-28* and *Cumberland B-55* wells, but with so little of the section drilled it is not surprising that a source rock has yet to be identified. Based on depth of burial it is expected that the Egret Member, if present, would be overmature (Sinclair et al, 1992). Another possible source rock is the equivalent of the organic rich Lower Tertiary shales that were encountered in *Nautilus C-92*, in the Jeanne d'Arc basin. These shales were immature in the Jeanne d'Arc but could have entered the oil window as the Tertiary wedge thickens into the Orphan basin. It is also possible that the equivalent of the Upper Cretaceous Markland Shale, which sourced the gas off Labrador, could be preserved in the deeper parts of the basin. The Carboniferous sediments encountered in the Orphan basin (see figure 5.7) have been described as meta-sediments in some wells but it is the subject of some debate whether these wells are representative of the Carboniferous throughout the basin. In western Newfoundland, rich Carboniferous source rocks are preserved adjacent to sediments that have been locally "cooked". Possible sources for reservoir quality sands would be the Bonavista Platform to the west and the Orphan Knoll and Flemish Cap to the east. If the ridges arose at the same time as the Ridge Complex to the south it is likely that they were once covered by Lower Cretaceous (and possibly Jurassic) sediment that was later eroded and deposited along the flanks (figure 5.6). Seismic data, although of poor quality, support this interpretation, suggesting that the flanks of the ridges may present better drilling targets than the crests, in the central part of the basin.

Orphan Basin
Exploration Wells 7

Source Rock:
- Not yet identified

Possible Source Rocks:
- Lower Tertiary shales
- Lower Cretaceous Markland Shale
- Upper Jurassic Egret Shale
- Carboniferous Shales

Reservoir Quality Sands Encountered Wells:
- Oligiocene Sandstones
- Base of Tertiary fans and channel fill (South Mara equivalent)
- Fox Harbour/Otter Bay sandstones (Upper Cretaceous)

Other Possible Sandstone Reservoirs
- Lower Cretaceous sandstones were encountered in the Linnet E-63 well and are expected to exist in downdip locations where they were may have been shed from the crests of local highs
- Jurassic sandstones may also have been shed from local highs and deposited on the flanks

Play Types
- Drape of Lower Tertiary Sands over basement horsts and tilted fault blocks
- Stratigraphic pinchouts Lower Cretaceous and Jurassic on the flanks of basement highs
- Prograding wedges, fans and channel sandstones at the base of Tertiary

Table 5.3

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Table 5.3

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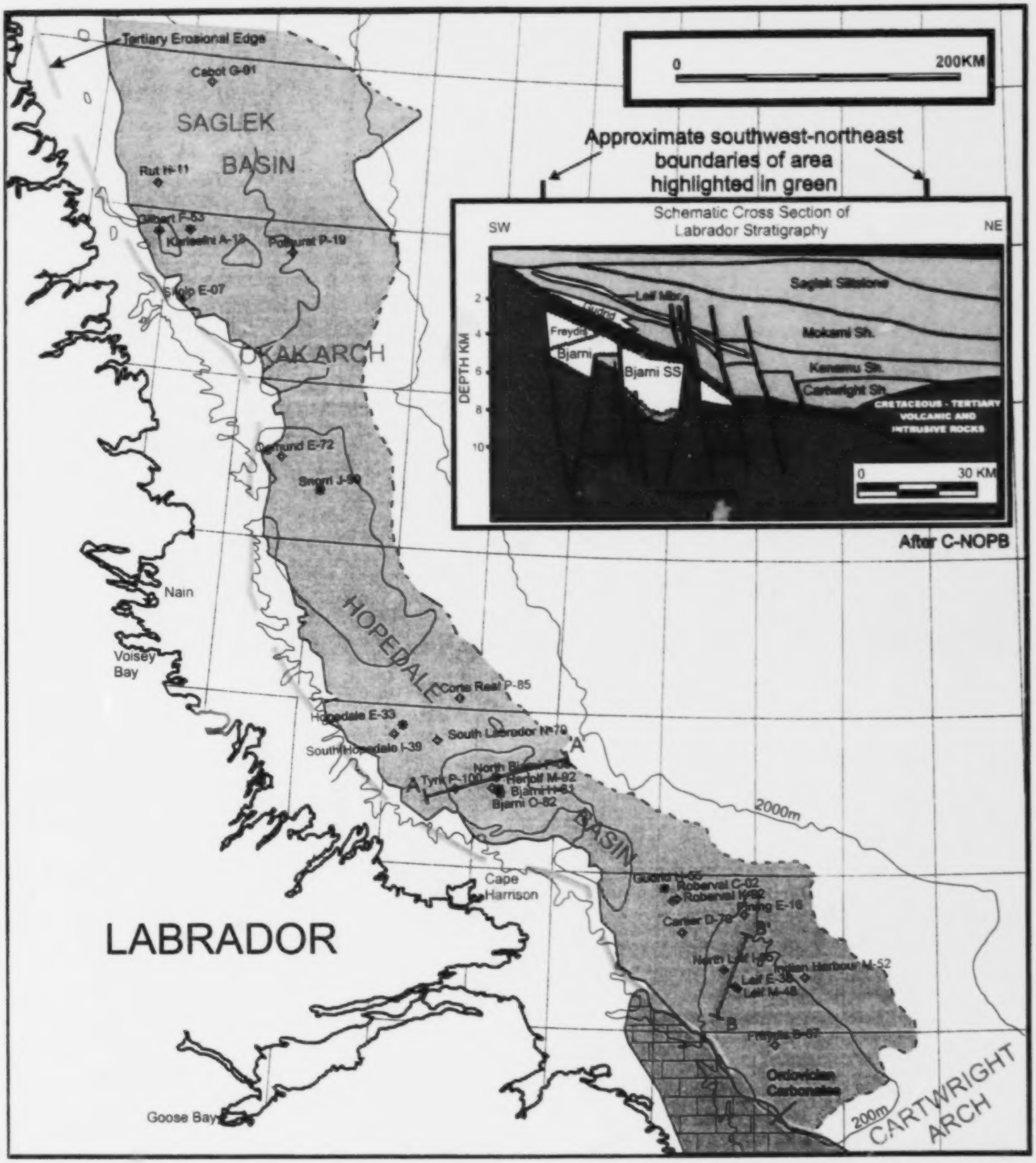
Labrador Shelf


0
200KM
Tertiary Erosional Edge
Cabot G-91
SAGLEK
BASIN
Rut H-11
Gilbert F-53
Karlsefni A-13
Pothurst P-19
Skolp E-07
OKAK ARCH
Ogmund E-72
Snorri J-90
Nain
Voisey Bay
HOPEDALE
Corte Real P-85
Hopedale E-33
South Hopedale I-39
South Labrador N-79
A'
North Bjarni F-06
Tyrk P-100
Herjolf M-92
Bjarni H-81
Bjarni O-82
A
BASIN
2000m
Cape Harrison
Gudrid H-55
Roberval C-02
Roberval K-92
Pining E-16
B'
Cartier D-70
North Leif I-05
Indian Harbour M-52
Leif E-38
Leif M-48
B
Freydis B-87
Ordovician Carbonates
200m
CARTWRIGHT ARCH
LABRADOR
Goose Bay
Schematic Cross Section of Labrador Stratigraphy
SW
NE
DEPTH KM
2
4
6
8
10
Saglek Siltstone
Leif Mbr.
Gudrid
Freydis
Bjarni
Bjarni SS
Mokami Sh.
Kenamu Sh.
Cartwright Sh.
CRETACEOUS - TERTIARY VOLCANIC AND INTRUSIVE ROCKS
0
30 KM

Approximate southwest-northeast boundaries of area highlighted in green

After C-NOPB

Simplified map of Mesozoic cover offshore Labrador, showing significant discoveries and shows. (Modified after top Cartright Formation Map, GSC Labrador Sea Atlas, 1989) Remnants of the Lower Paleozoic carbonate shelf that extend beneath the Hopedale Basin have tested high rates of natural gas. The inset shows the generalized structural and stratigraphic framework.

Figure 6.1

Section 6

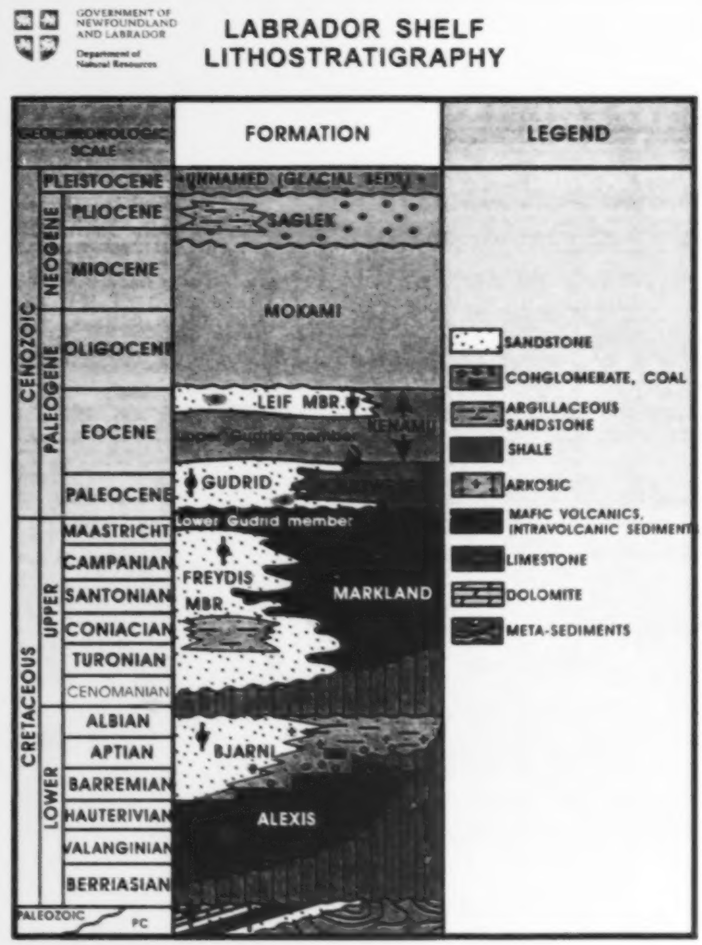
Labrador Shelf

The Labrador Shelf includes the Saglek and Hopedale basins, that are separated by an easterly-trending basement high (the Okak Arch) with thinned Mesozoic cover (figure 6.1). To date, all the Labrador hydrocarbon discoveries are located in the Hopedale Basin, although gas shows have been recorded in some of the Saglek wells (e.g. *Karlsefni A-13*). The discoveries contain estimated recoverable resources of 4.2 Tcf of natural gas and 123 million barrels of NGL (C-NOPB). The largest single discovery is North Bjarni, with 2.2 Tcf of gas and 82 million barrels of NGL (figure 6.3). The undiscovered Labrador Shelf natural gas potential has been estimated at 22 trillion cubic feet (Drummond, 1988).

A number of Cretaceous to Paleocene sandstone reservoirs, in particular the Bjarni, Freydis and Gudrid sandstones, mark the Hopedale Basin (figure 6.2). The key trapping mechanisms are drape of Cretaceous and Lower Tertiary sands over uplifted basement blocks, and pinchouts against the flanks (figures 6.3 and 6.4). A Paleozoic carbonate, (believed to be an erosional remnant of the Cambro-Ordovician platform observed in the Anticosti Basin) underlies parts of the Hopedale Basin, and tested gas at high rates at *Hopedale E-33* (19.5MMcf/d) and *Gudrid H-55* (8.1 MMcf/d). The Markland Shale is rich in terrestrially derived organic matter and is believed to be the primary source rock for the discovered gas.

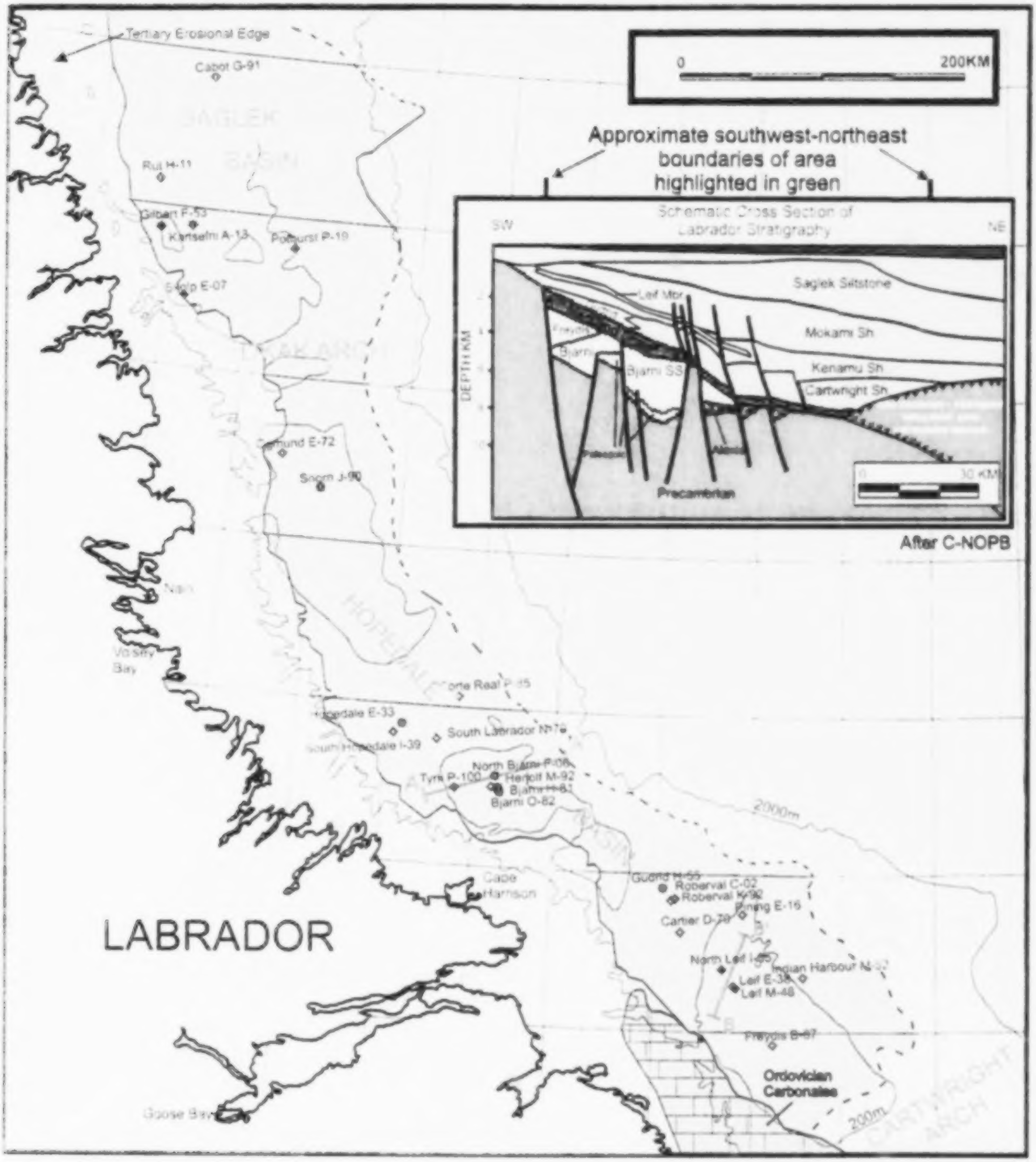
With only 21 wells drilled and 4.2 Tcf discovered, the Hopedale Basin is obviously a favourable geological province for the accumulation of large quantities of natural gas. However, development of Labrador Shelf gas faces the challenges of a short drilling season (limited to about 3 months by pack ice and weather), high iceberg traffic and remoteness from major markets. The Department of Mines and Energy studied the feasibility of developing Labrador's gas resources in 1992 and concluded that certain critical technological advances would be required, including: improved pipeline trenching methods to protect against iceberg scouring, and long distance multiphase and metering technologies.

Figure 6.2


GOVERNMENT OF NEWFOUNDLAND AND LABRADOR
Department of Natural Resources
LABRADOR SHELF LITHOSTRATIGRAPHY
GEOCHRONOLOGIC SCALE
FORMATION
LEGEND
CENOZOIC
NEOGENE
PALEOGENE
PLEISTOCENE
PLIOCENE
MIOCENE
OLIGOCENE
EOCENE
PALEOCENE
CRETACEOUS
UPPER
LOWER
MAASTRICHT
CAMPANIAN
SANTONIAN
CONIACIAN
TURONIAN
CENOMANIAN
ALBIAN
APTIAN
BARREMIAN
HAUTERIVIAN
VALANGINIAN
BERRIASIAN
PALEOZOIC
PC
UNNAMED (GLACIAL SEDS)
SAGLEK
MOKAMI
LEIF MBR.
KENAMU
Upper Gudrid member
GUDRID
Lower Gudrid member
FREYDIS MBR.
MARKLAND
BJARNI
ALEXIS
SANDSTONE
CONGLOMERATE, COAL
ARGILLACEOUS SANDSTONE
SHALE
ARKOSIC
MAFIC VOLCANICS, INTRAVOLCANIC SEDIMENTS
LIMESTONE
DOLOMITE
META-SEDIMENTS

After C-NOPB/McWhae et al 1980

Labrador Shelf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CARTWRIGHT ARCH
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Goose Bay
0
200KM
Approximate southwest-northeast boundaries of area highlighted in green
Schematic Cross Section of Labrador Stratigraphy
SW
NE
DEPTH KM
Saglek Siltstone
Leif Mbr
Freydis
Bjarni
Mokami Sh
Bjarni SS
Kenamu Sh
Cartwright Sh
Paleozoic
Alexis
Precambrian
0
30 KM
After C-NOPB

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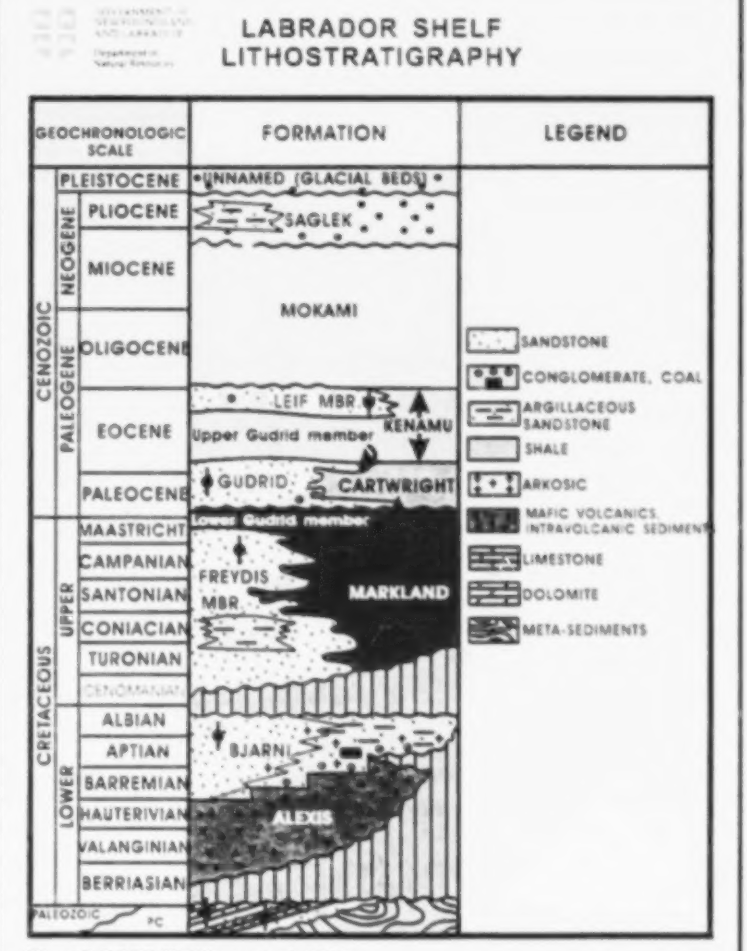
LABRADOR SHELF
LITHOSTRATIGRAPHY
GEOCHRONOLOGIC SCALE
FORMATION
LEGEND
CENOZOIC
NEOGENE
PALEOGENE
PLEISTOCENE
PLIOCENE
MIOCENE
OLIGOCENE
EOCENE
PALEOCENE
CRETACEOUS
UPPER
LOWER
MAASTRICHT
CAMPANIAN
SANTONIAN
CONIACIAN
TURONIAN
CENOMANIAN
ALBIAN
APTIAN
BARREMIAN
HAUTERIVIAN
VALANGINIAN
BERRIASIAN
PALEOZOIC
PC
UNNAMED (GLACIAL BEDS)
SAGLEK
MOKAMI
LEIF MBR.
KENAMU
Upper Gudrid member
GUDRID
CARTWRIGHT
Lower Gudrid member
FREYDIS MBR.
MARKLAND
BJARNI
ALEXIS
SANDSTONE
CONGLOMERATE, COAL
ARGILLACEOUS SANDSTONE
SHALE
ARKOSIC
MAFIC VOLCANICS INTRAVOLCANIC SEDIMENTS
LIMESTONE
DOLOMITE
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After C-NOPB/McWhae et al 1980

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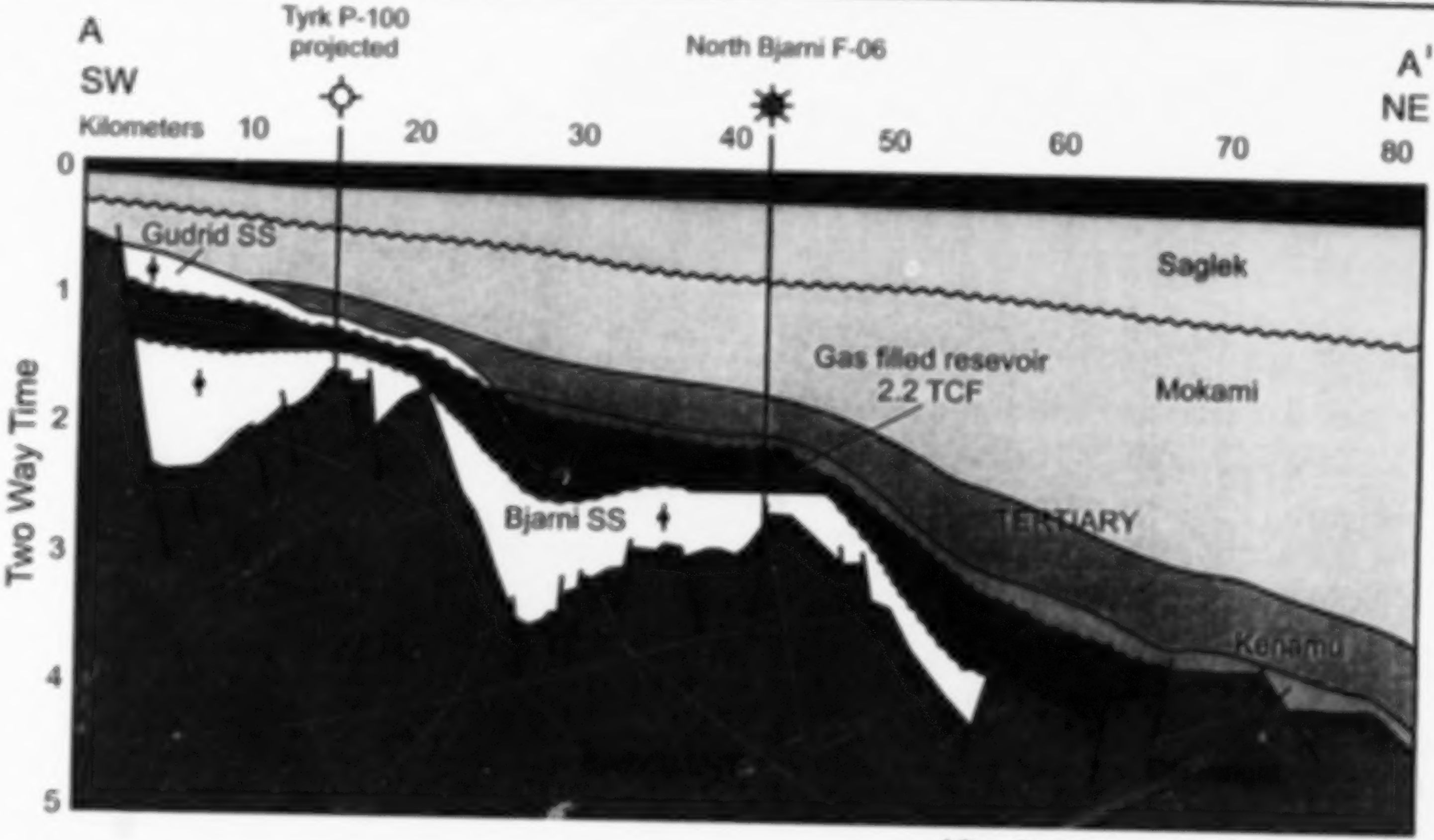
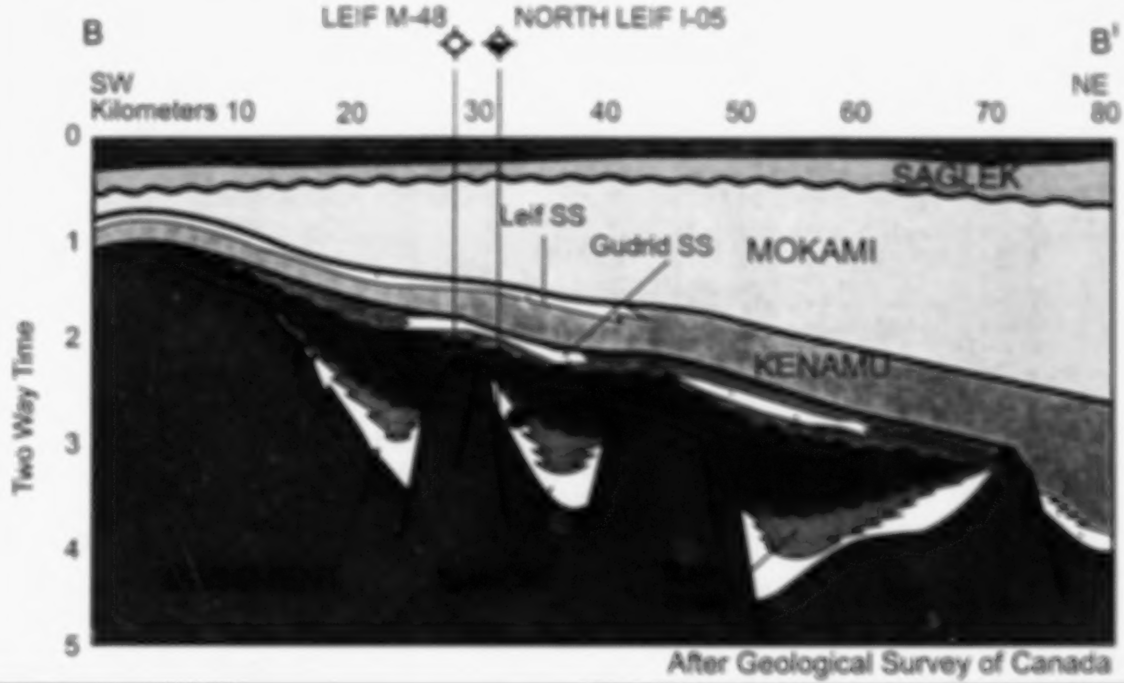
Figure 6.3


A
SW
Kilometers
10
20
30
40
50
60
70
80
A'
NE
Tyrk P-100
projected
North Bjarni F-06
Two Way Time
0
1
2
3
4
5
Gudrid SS
Saglek
Mokami
Gas filled resevoir
2.2 TCF
Bjarni SS
TERTIARY
Kenamu

After Geological Survey of Canada

North Bjarni Cross-section: The North Bjarni structure contains over 2.2 Tcf of natural gas - more than half of all the Labrador Gas discovered to date. When it was drilled in 1980 it intersected the thickest continuous pay section in Canadian history (194 Metres). The gas/water contact is visible as a seismic flat spot and indicates that the structure is filled to the spill point. See Figure 6.1 for section location.

Figure 6.4


B
LEIF M-48
NORTH LEIF I-05
B'
SW
NE
Kilometers 10
20
30
40
50
60
70
80
0
1
2
3
4
5
Two Way Time
SAGLEK
Leif SS
Gudrid SS
MOKAMI
KENAMU

After Geological Survey of Canada

North Lief Cross-Section: North Leif I-05 is the only Labrador well to have recovered oil on drill stem test (32° API, waxy oil). This cross-section re-enforces the fact that structures in this area that were devoid of reservoir on the crest, can have reservoir quality sands on the flanks. See figure 6.1 for section location.

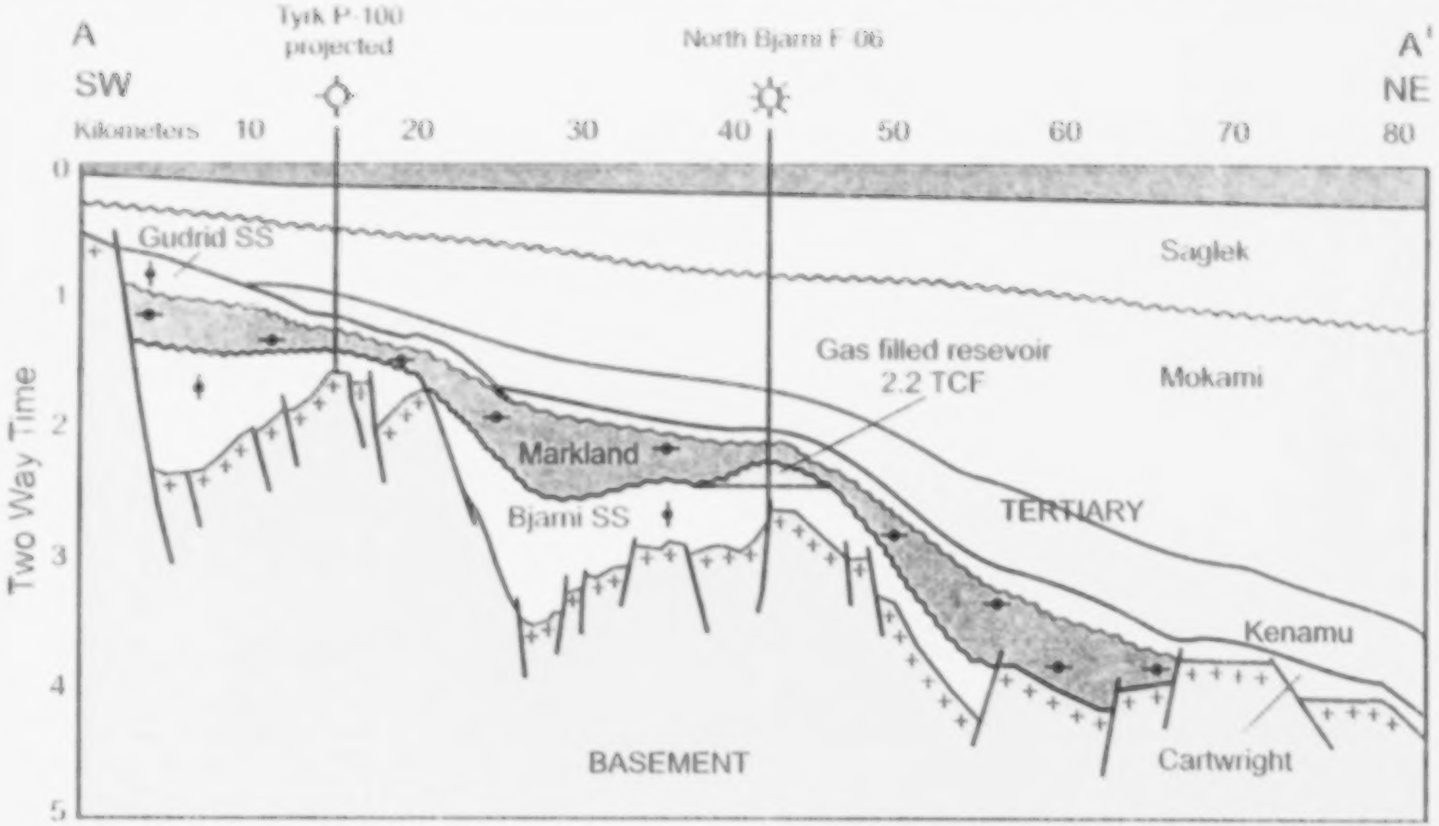
Labrador Shelf		**Source Rock:**	Markland Shale
Exploration Wells	27	**Reservoirs:**	Tertiary sandstones (Leif and Gudrid Members), U. Cretaceous Sandstones (Freydis Member), L. Cretaceous Sandstones (Bjarni Formation), Lower Paleozoic Carbonates
Significant Discoveries	5		
Oil Shows	1		

PLAY TYPES:

- Crests of basements highs
    - with preserved L. Cretaceous sands
    - with preserved Lower Paleozoic Carbonates
- Drape of Tertiary and Cretaceous sands over tilted fault blocks
- Pinchout of the Bjarni sands against flanks of a tilted fault blocks

Table 6.1

Figure 6.3


A
SW
Tyrk P-100
projected
North Bjarni F-06
A'
NE
Kilometers
10
20
30
40
50
60
70
80
Two Way Time
0
1
2
3
4
5
Gudrid SS
Saglek
Mokami
Gas filled resevoir
2.2 TCF
Markland
Bjarni SS
TERTIARY
Kenamu
Cartwright
BASEMENT

After Geological Survey of Canada

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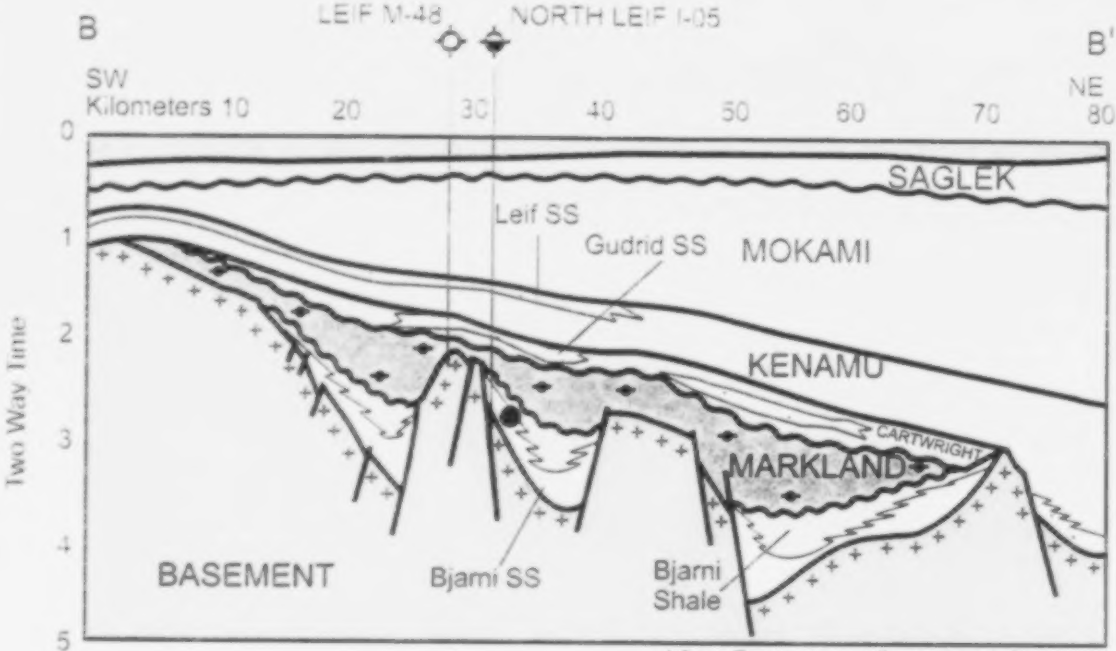
B
LEIF M-48
NORTH LEIF I-05
B'
SW
Kilometers 10
20
30
40
50
60
70
NE
80
0
1
2
3
4
5
Two Way Time
SAGLEK
Leif SS
Gudrid SS
MOKAMI
KENAMU
CARTWRIGHT
MARKLAND
BASEMENT
Bjarni SS
Bjarni Shale

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Labrador Shelf	
Exploration Wells	27
Significant Discoveries	5
Oil Shows	1

Source Rock: Markland Shale

Reservoirs: Tertiary sandstones (Leif and Gudrid Members), U. Cretaceous Sandstones (Freydis Member), L. Cretaceous Sandstones (Bjarni Formation), Lower Paleozoic Carbonates

PLAY TYPES:

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  - with preserved Lower Paleozoic Carbonates
- Drape of Tertiary and Cretaceous sands over tilted fault blocks
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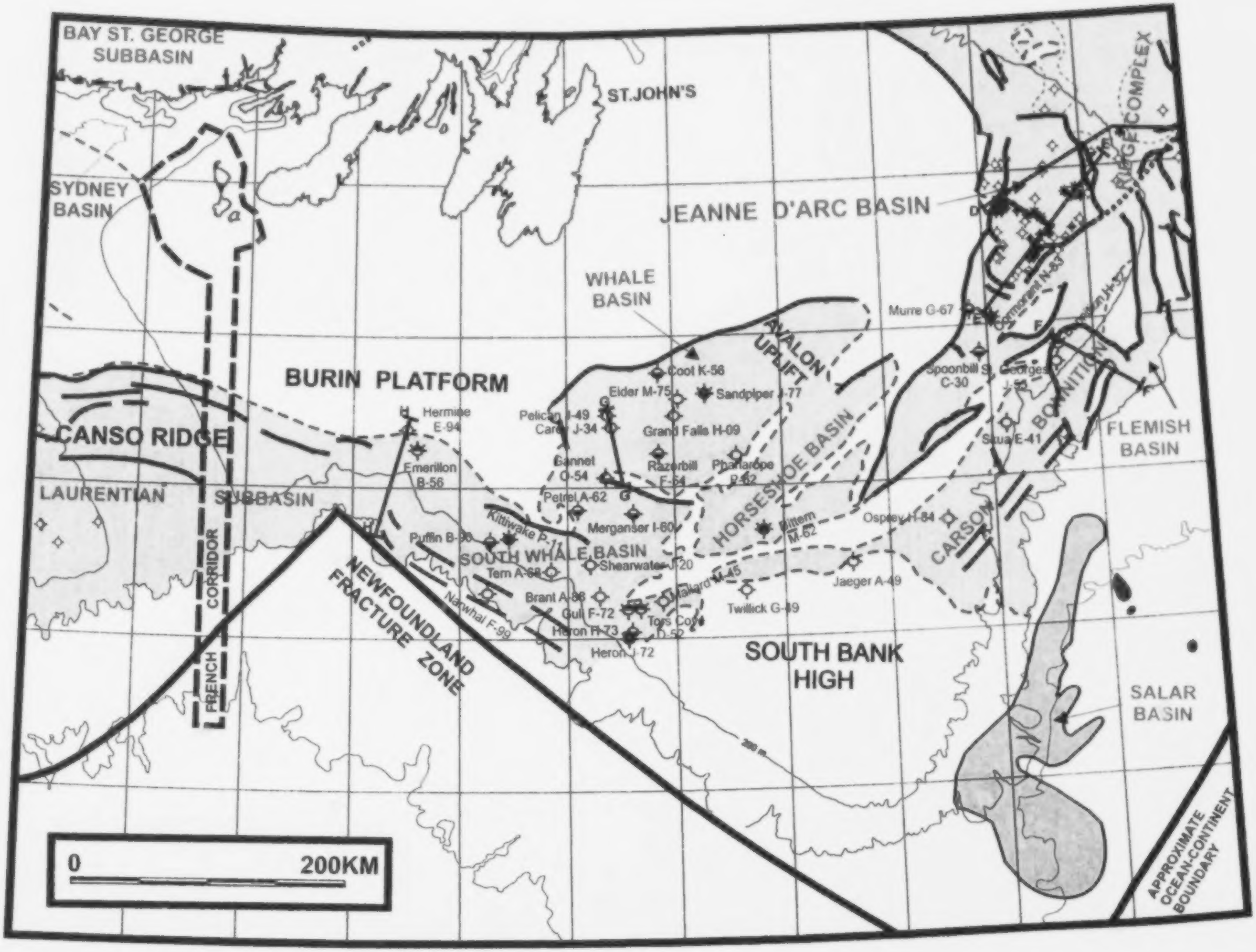
Table 6.1

Basins of the Southern Grand Banks


BAY ST. GEORGE SUBBASIN
ST.JOHN'S
SYDNEY BASIN
JEANNE D'ARC BASIN
RIDGE COMPLEX
WHALE BASIN
AVALON UPLIFT
BURIN PLATFORM
CANSO RIDGE
LAURENTIAN SUBBASIN
FRENCH CORRIDOR
NEWFOUNDLAND FRACTURE ZONE
SOUTH WHALE BASIN
HORSESHOE BASIN
CARSON
BONNITION
FLEMISH BASIN
SOUTH BANK HIGH
SALAR BASIN
APPROXIMATE OCEAN-CONTINENT BOUNDARY
Murre G-67
Cormorant N-83
Spoonbill C-30
St. Georges J-55
Sula E-41
Coot K-56
Elder M-75
Sandpiper J-77
Pelican J-49
Cape J-34
Grand Falls H-09
Razorbill F-54
Phalarope P-62
Gannet O-54
Petrel A-62
Merganser I-60
Bittern M-62
Osprey H-84
Hermine E-94
Emerillon B-56
Puffin B-90
Kittiwake P-11
Tern A-68
Shearwater J-20
Mallard M-45
Jaeger A-49
Twillick G-49
Brant A-86
Gull F-72
Tors Cove D-52
Heron H-73
Heron J-72
Narwhal F-99
200 m
0
200KM

Modified after: Canada-Newfoundland Offshore Petroleum Board and Geological Survey of Canada

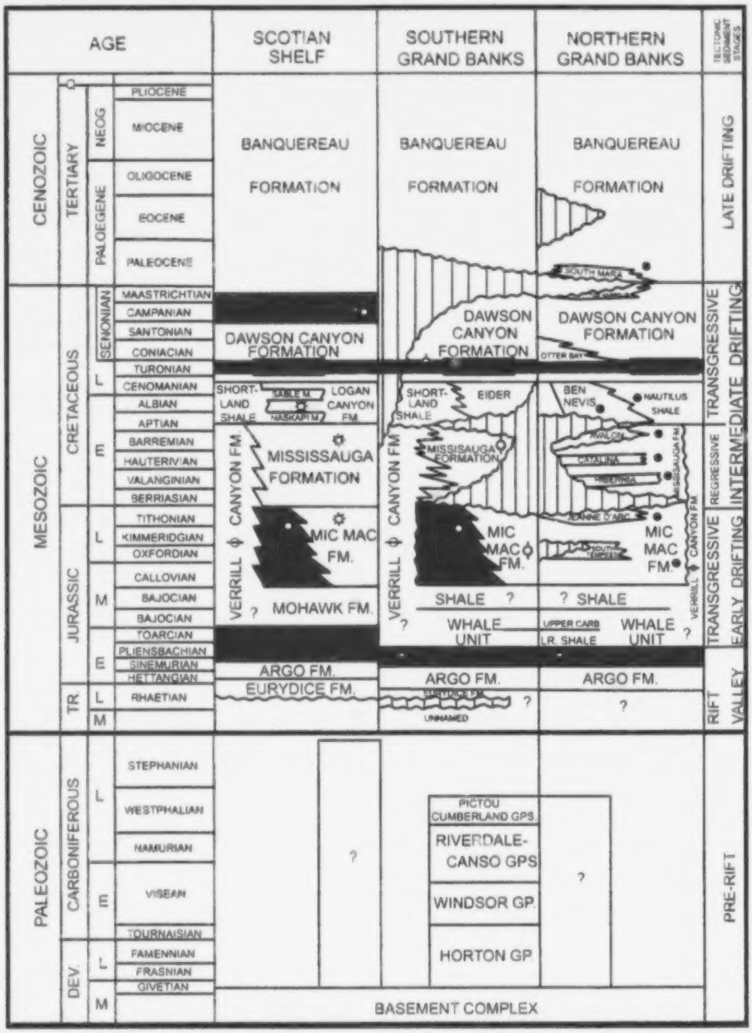
Figure 7.1

Section 7 Southern Grand Banks

7.1 Southwest Grand Banks

The southwest Grand Banks include several Mesozoic basins (namely the Whale and Horseshoe basins and the South Whale and Laurentian subbasins; see figure 7.1), that are extensively underlain by Carboniferous sediments. The Mesozoic strata underlie a thick Tertiary wedge that covers most of the continental shelf and progrades seaward over the shelf edge (figures 7.2 & 7.3). The GSC's depth to basement map of the area indicates an additional basin, the Salar Basin, in deeper water (figures 3.1 & 7.1) of which little is currently known. Drilling has not occurred in the Laurentian subbasin because the area has been the subject of jurisdictional disputes - first between Canada and France (the islands of St. Pierre and Miquelon in this area belong to France) and more recently between the provinces of Newfoundland and Nova Scotia. The petroleum rights (issued in the 1960's but effectively under "moratorium" since that time) are held by Mobil, Gulf and Imperial. The Geological Survey of Canada has studied the area and estimates that it contains 8 to 9 Tcf of natural gas and 600 to 700 million barrels of oil (MacLean and Wade, 1990). The companies holding the lands in the basin have recently been acquiring seismic data in preparation for a resolution of the interprovincial boundary dispute - expected in the spring of 2002.

Figure 7.2


AGE
SCOTIAN SHELF
SOUTHERN GRAND BANKS
NORTHERN GRAND BANKS
TECTONIC SEDIMENT STAGES
CENOZOIC
TERTIARY
NEOG
PALEOGENE
PLIOCENE
MIOCENE
OLIGOCENE
EOCENE
PALEOCENE
MESOZOIC
CRETACEOUS
SENONIAN
MAASTRICHTIAN
CAMPANIAN
SANTONIAN
CONIACIAN
TURONIAN
CENOMANIAN
ALBIAN
APTIAN
BARREMIAN
HAUTERIVIAN
VALANGINIAN
BERRIASIAN
JURASSIC
TITHONIAN
KIMMERIDGIAN
OXFORDIAN
CALLOVIAN
BAJOCIAN
BAJOCIAN
TOARCIAN
PLIENSBACHIAN
SINEMURIAN
HETTANGIAN
TR
RHAETIAN
PALEOZOIC
CARBONIFEROUS
STEPHANIAN
WESTPHALIAN
NAMURIAN
VISEAN
TOURNAISIAN
DEV.
FAMENNIAN
FRASNIAN
GIVETIAN
L
E
M
BANQUEREAU FORMATION
BANQUEREAU FORMATION
BANQUEREAU FORMATION
SOUTH MARA
DAWSON CANYON FORMATION
DAWSON CANYON FORMATION
DAWSON CANYON FORMATION
OTTER BAY
SHORT-LAND SHALE
SABLE M.
NASKAPI M.
LOGAN CANYON FM
SHORT-LAND SHALE
EIDER
BEN NEVIS
NAUTILUS SHALE
MISSISSAUGA FORMATION
MISSISSAUGA FORMATION
MISSISSAUGA FM
AVALON
CATALINA
HIBERNIA
JEANNE D'ARC
VERRILL CANYON FM
VERRILL CANYON FM
VERRILL CANYON FM
MIC MAC FM.
MIC MAC FM.
MIC MAC FM.
SOUTH TEMPEST
MOHAWK FM.
SHALE
SHALE
WHALE UNIT
WHALE UNIT
UPPER CARB
LR. SHALE
ARGO FM.
ARGO FM.
ARGO FM.
EURYDICE FM.
EURYDICE FM.
UNNAMED
PICTOU CUMBERLAND GPS.
RIVERDALE-CANSO GPS
WINDSOR GP.
HORTON GP.
BASEMENT COMPLEX
?
LATE DRIFTING
TRANSGRESSIVE
INTERMEDIATE DRIFTING
REGRESSIVE
TRANSGRESSIVE
EARLY DRIFTING
RIFT VALLEY
PRE-RIFT

After Northcor Energy Report 1984 & MacLean and Wade, 1990

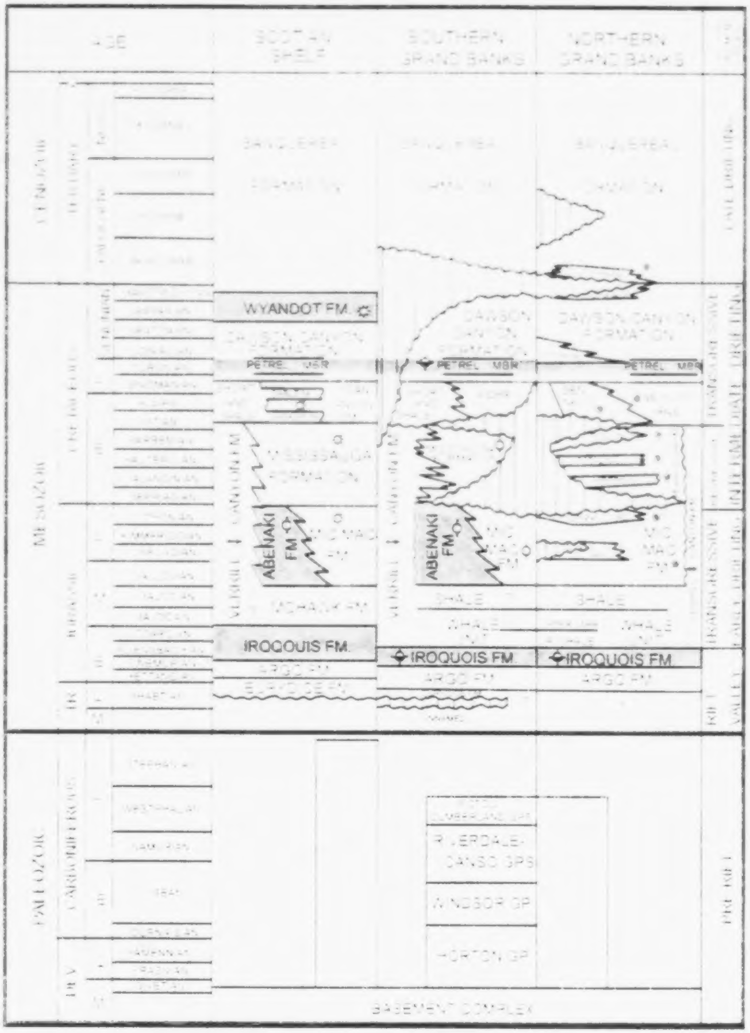
Comparitive stratigraphy of Scotian Shelf, Southern Grand Banks and Northern Grand Banks.

Section 7 Southern Grand Banks

7.1 Southwest Grand Banks

The southwest Grand Banks include several Mesozoic basins (namely the Whale and Horseshoe basins and the South Whale and Laurentian subbasins, see figure 7.1c) that are extensively underlain by Carboniferous sediments. The Mesozoic strata underlie a thick Tertiary wedge that covers most of the continental shelf and progrades seaward over the shelf edge (figures 7.2 & 7.3). The GSC's depth to basement map of the area indicates an additional basin, the Salar Basin, in deeper water (figures 3.1 & 7.1) of which little is currently known. Drilling has not occurred in the Laurentian subbasin because the area has been the subject of jurisdictional disputes (first between Canada and France (the islands of St Pierre and Miquelon in this area belong to France) and more recently between the provinces of Newfoundland and Nova Scotia. The petroleum rights (issued in the 1960s but effectively under "moratorium" since that time) are held by Mobil, Gulf and Imperial. The Geological Survey of Canada has studied the area and estimates that it contains 8 to 9 Tcf of natural gas and 600 to 700 million barrels of oil (MacLean and Wade, 1990). The companies holding the lands in the basin have recently been acquiring seismic data in preparation for a resolution of the interprovincial boundary dispute expected in the spring of 2002.

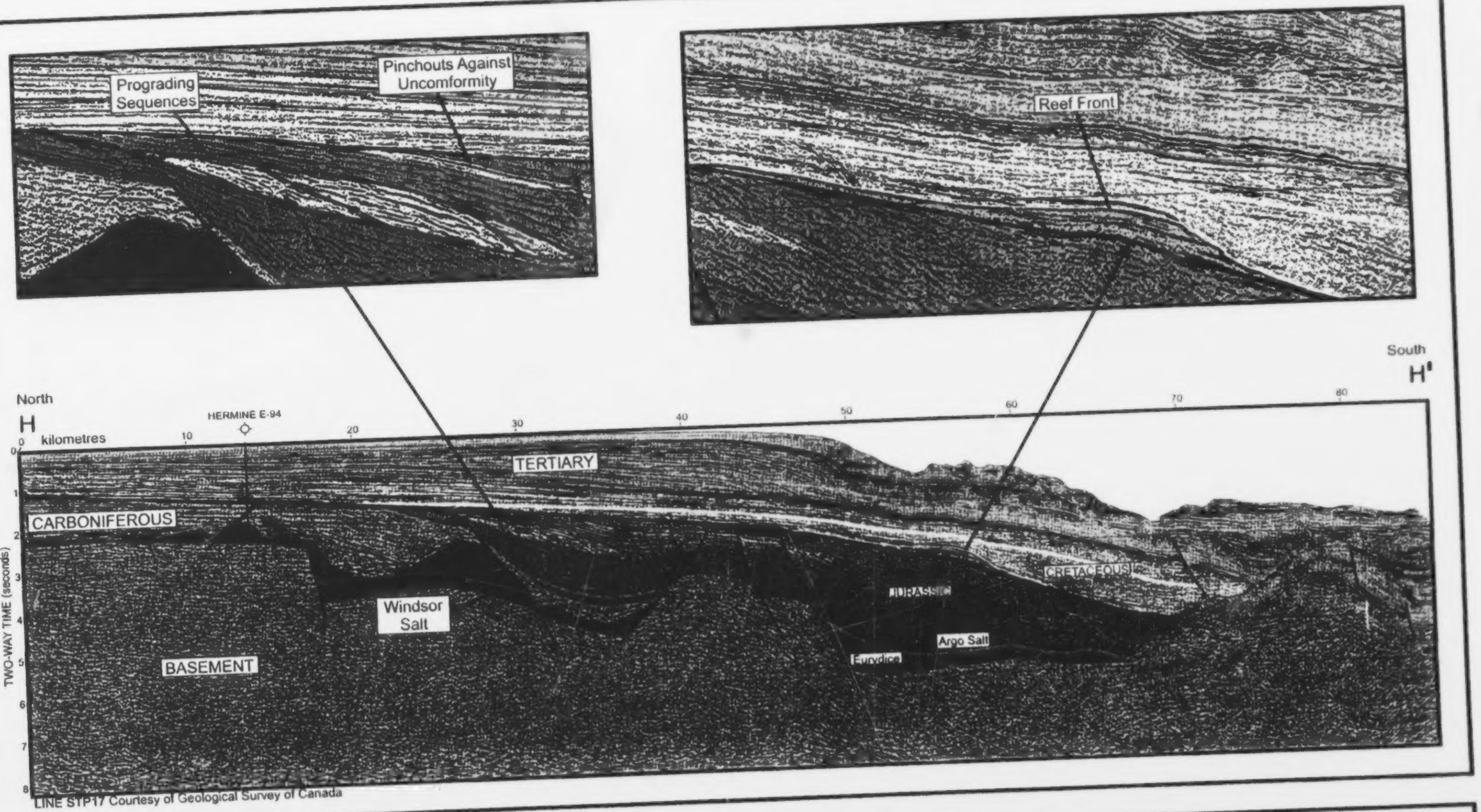
Figure 7.2


AGE
SCOTIAN SHELF
SOUTHERN GRAND BANKS
NORTHERN GRAND BANKS
CENOZOIC
TERTIARY
MESOZOIC
CRETACEOUS
JURASSIC
TR
PALEOZOIC
CARBONIFEROUS
DEV
BANQUEREAU FORMATION
WYANDOT FM.
DAWSON CANYON FORMATION
PETREL MBR
MISSISSAUGA FORMATION
ABENAKI FM
MIC MAC FM
VERRILL CANYON FM
MOHAWK FM
SHALE
WHALE UNIT
IROQUOIS FM.
ARGO FM
EURYDICE FM
RIVERDALE-CANSO GPS
WINDSOR GP
HORTON GP
BASEMENT COMPLEX
LATE DRIFTING
TRANSGRESSIVE DRIFTING
INTERMEDIATE DRIFTING
TRANSGRESSIVE EARLY DRIFTING
RIFT VALLEY
PRE-RIFT

After Northcor Energy Report 1984 & MacLean and Wade 1990

Comparative stratigraphy of Scotian Shelf, Southern Grand Banks and Northern Grand Banks.

South Whale Basin


Prograding Sequences
Pinchouts Against Uncomformity
Reef Front
North
H
kilometres
HERMINE E-94
0
10
20
30
40
50
60
70
80
South
H'
TWO-WAY TIME (seconds)
1
2
3
4
5
6
7
8
TERTIARY
CARBONIFEROUS
Windsor Salt
BASEMENT
JURASSIC
CRETACEOUS
Argo Salt
Eurydice

LINE STP17 Courtesy of Geological Survey of Canada

Seismic line STP17: indicates a thick Jurassic section down lapping into a restricted basin bounded to the south by a basement ridge. A number of trapping mechanisms are evident including a reef front play at what is believed to be the Abenaki level. Similar reef-like character has been observed on seismic data up to 35 km to the west, suggesting the possibility of a large regional play. The basement high interpreted in the central part of the section appears on several widely spaced lines, presenting the possibility of a large linear closure. Interpreted seismic section provided by GSC. Additional interpretation by Dept of Mines and Energy. See figure 7.1 for section location.

Figure 7.3

Section 7.2

South Whale Subbasin

The South Whale subbasin was the first to see the drill bit in the Newfoundland and Labrador offshore area. The relatively ice-free and shallow waters, combined with an abundance of salt piercement features that were familiar trapping mechanisms in the Gulf of Mexico, made it an attractive place to begin exploratory drilling. Twenty seven wells were drilled in the basins of the southwest Grand Banks basins between 1966 and 1974, of which 15 were located in the South Whale subbasin. Although good reservoirs and several oil and gas shows (figure 7.1) gave encouragement, no discoveries resulted. It is noteworthy, however, that 11 of the 15 wells in South Whale were drilled over the crests of and adjacent salt domes, or on basement-cored ridges with thinned sedimentary cover. Drilling over and adjacent to salt domes did not prove to be an effective strategy, possibly because the latest movement of the Lower Jurassic Argo Salt postdated the migration of hydrocarbons. This approach also resulted in very limited penetration of the sedimentary package, and so a great deal remains unknown about the off-structure basin stratigraphy. The southwest Grand Banks basins were connected to the Jeanne d'Arc Basin from the onset of rifting in the Late Triassic until the rise of the Avalon uplift in Late Jurassic, providing the opportunity for deposition of similar Jurassic reservoirs and source rocks as in the Jeanne d'Arc. The Late Jurassic Kimmeridgian shale has not been intersected in any of the wells and, as such, a major source rock for the basin has yet to be identified . However, given the number of oil and gas shows and similar tectonic history to both the northern Grand Banks and the Scotian Shelf, it is likely that the equivalent of the Egret Member (which has sourced the Jeanne d'Arc basin) and/or the Verrill Canyon shales (which have sourced the Scotian Shelf) are present in the deeper parts of the South Whale subbasin.

The Avalon Uplift resulted in erosion of older Jurassic sediments in the Whale and Horseshoe basins and the shedding of erosional detritus into the surrounding basins; likely including the Jeanne d'Arc, Carson/Bonnition and South Whale depocentres. After separation from the northern Grand Banks by the Avalon uplift, the South Whale subbasin evolved throughout the Cretaceous as a passive margin, similar to the Scotian Shelf.

A tectonic factor that differentiates the southwest Grand Banks from the Scotian Shelf is that the SW Grand Banks was influenced by strike slip movement along the Newfoundland Transform throughout the Jurassic. This is likely the cause of the large basement ridges (observed on seismic) that run parallel to the shelf, outboard of the main Jurassic depocentres (figure 7.3). Kerr (1985) speculates that such ridges could have provided the restricted marine conditions necessary to create an oil prone source rock, as opposed to the gas prone source rocks of the Scotian Shelf.

The South Whale subbasin contains the equivalent of Micmac and Mississauga sandstone reservoirs that have been the key producers in the Scotian Basin. Additionally, seismic line STP17 (figure 7.3) indicates the possibility of an Abenaki reef-front play. The Abenaki reef-front offshore Nova Scotia is known to contain thick porous sections in the Demascota and Bonnet wells (Eliuk, 1978; Harvey & MacDonald, 1990). Indeed, PanCanadian has recently announced a major gas discovery beneath the Panuke oil field. The sandstone reservoir of the Panuke field is known to drape over the Abenaki carbonate reef front (Harvey and MacDonald, 1990). PanCanadian has since confirmed that the discovery is within a Jurassic reef front, by a map and cross-section published on its web site.

Another possible stratigraphic play identified on seismic line STP17 is a large undeformed marginal marine progradational package within the Jurassic. Clearly there is no shortage of reservoir or trapping possibilities in the South Whale basin, and as such it must be considered one of the more prospective areas for future exploration.

South Whale Subbasin

Exploration Wells	15
• 9 on salt features	
• 2 on ridges	
Oil Shows	4
Gas Shows	3
Oil & Gas Shows	2

Source Rock:
- Not yet identified

Possible Source Rocks:
Verrill Canyon Shale
Kimmeridgian Shale (Egret equivalent)

Reservoirs:
Lower Tertiary Sandstones
Logan Canyon Sandstones (Eider)
Mississauga Sandstones
Micmac Sandstones
Abenaki Reef Front
Iroquois Carbonate

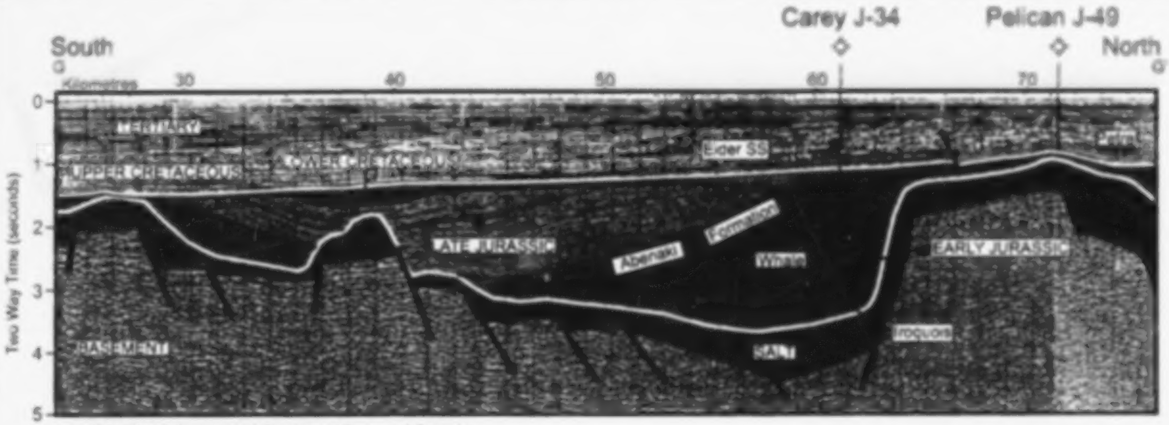
Play Concepts
- Subcrop of Jurassic sandstones below the base-of-Tertiary unconformity
- Late Jurassic sandstones (MicMac Formation) draped over the horst feature that strikes along the basin for tens of kilometers (Figure 7.3)
- Stratigraphic traps in the base of Tertiary sandstones (fans, channel fill, etc.)
- Drape of Eider sandstone over deeper structures (equivalent to Upper Logan Canyon in the Scotian Basin)
- Drape of known Jurassic and Lower Cretaceous sandstones (Micmac, Mississauga, Eider) and Carbonates (Iroquois and Abenaki) over deep seated structures such as salt swells in the Argo Formation and Windsor Group, and over basement highs.
- Rollover anticlines in the Jurassic/Cretaceous
- Marginal marine progradation sequence observed on seismic (See Figure 7.3)
- The Abenaki reef front play (See Figure 7.3)
- Drape of Mississauga and Eider sandstones over the Abenaki reef front
- Fore-reef detritus pinchouts at the toe of the reef front slope
- Subcrop of Micmac and Mississauga sandstones against unconformities
- Lower Tertiary turbidites below the shelf break and adjacent to large ridges (such as the Narwhal Ridge) that run parallel to the continental slope

Table 7.1

Section 7.3
Whale and Horseshoe Basins

The Whale and Horseshoe Basins are considered to be less prospective than other southwest Grand Banks basins because they were subjected to extensive erosion of Jurassic sediments during the Avalon Uplift. However, the seismic line shown in figure 7.4 indicates that a thick Jurassic section is preserved in the southwestern part of the basin. The *Carey J-34* well encountered carbonates of the Abenaki Formation below the base of Cretaceous unconformity. The Upper Jurassic section to the south of *Carey J-34* could contain the sands and shales of the Rankin, Jeanne d'Arc and Fortune Bay Formations, including the Kimmeridgian source rock.

Figure 7.4


Carey J-34
Pelican J-49
South
G
North
G'
Kilometres
30
40
50
60
70
0
1
2
3
4
5
Two Way Time (seconds)
TERTIARY
UPPER CRETACEOUS
LOWER CRETACEOUS
Eider SS
LATE JURASSIC
Abenaki
Formation
Whale
EARLY JURASSIC
Iroquois
SALT
BASEMENT

Line EC 72-117 Courtesy of Geological Survey of Canada

Seismic section EC 72-117 and interpretation provided by Geological Survey of Canada. Additional interpretation by Department of Mines & Energy. See figure 7.1 for section location.

Whale and Horseshoe Basins	
Exploration Wells	13
Oil Shows	2
Oil & Gas Shows	2

Source Rock:

- Not Yet Identified

Possible Source Rocks:

- Verrill Canyon Formation
- Egret Member

Reservoirs:

- Lower Tertiary Sandstones
- Logan Canyon Sandstones (Eider)
- Missisauga Sandstones
- Mimac Sandstones
- Abernaki Carbonate Bank
- Iroquois Carbonate

Play Concepts

- Subcrop of Jurassic reservoir rocks against Avalon unconformity where the Eider is also closed or not present
- Drape of the Eider sandstone over deeper structures
- Drape of Jurassic reservoirs, that are not breached by the Eider, over deeper structures
- Faulting against regional dip of Jurassic reservoir rocks
- Drape and stratigraphic pinchout of lower Teritary reservoirs

Table 7.2

South Whale Subbasin

Exploration Wells	15
• 9 on salt features	
• 2 on ridges	
Oil Shows	4
Gas Shows	3
Oil & Gas Shows	2

Source Rock:

- Not yet identified

Possible Source Rocks:

Verrill Canyon Shale
Kimmeridgian Shale (Egret equivalent)

Reservoirs:

Lower Tertiary Sandstones
Logan Canyon Sandstones (Eider)
Mississauga Sandstones
Micmac Sandstones
Abenaki Reef Front
Iroquois Carbonate

Play Concepts

- Subcrop of Jurassic sandstones below the base-of-Tertiary unconformity
- Late Jurassic sandstones (MicMac Formation) draped over the horst feature that strikes along the basin for tens of kilometers (Figure 7.3)
- Stratigraphic traps in the base of Tertiary sandstones (fans, channel fill, etc.)
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- Drape of known Jurassic and Lower Cretaceous sandstones (Micmac, Mississauga, Eider) and Carbonates (Iroquois and Abenaki) over deep seated structures such as salt swells in the Argo Formation and Windsor Group, and over basement highs.
- Rollover anticlines in the Jurassic/Cretaceous
- Marginal marine progradation sequence observed on seismic (See Figure 7.3)
- The Abenaki reef front play (See Figure 7.3)
- Drape of Mississauga and Eider sandstones over the Abenaki reef front
- Fore-reef detritus pinchouts at the toe of the reef front slope
- Subcrop of Micmac and Mississauga sandstones against unconformities
- Lower Tertiary turbidites below the shelf break and adjacent to large ridges (such as the Narwhal Ridge) that run parallel to the continental slope

Table 7.1

Section 7.3

Whale and Horseshoe Basins

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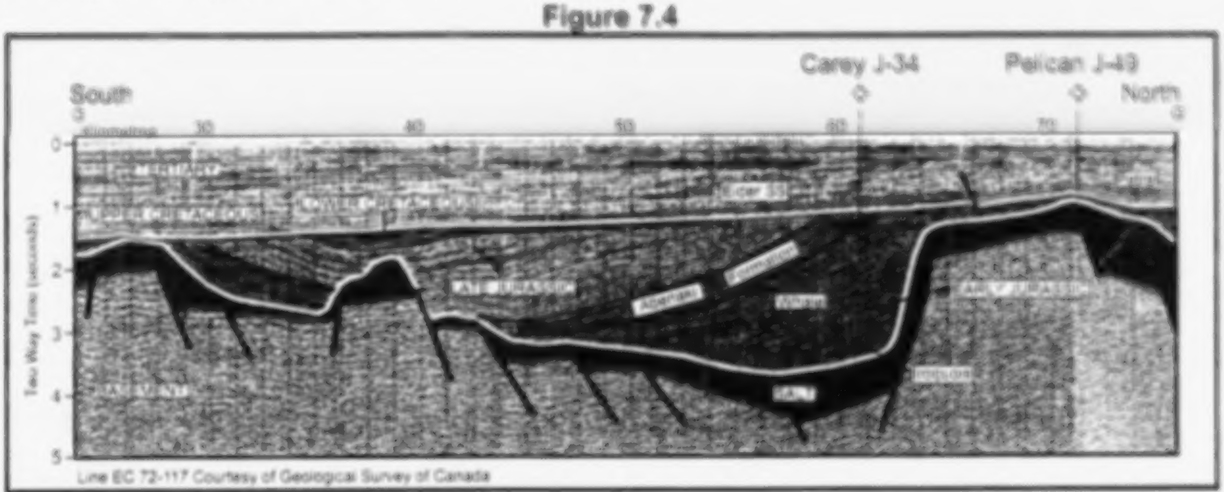
Figure 7.4


Carey J-34
Pelican J-49
South
North
kilometres
30
40
50
60
70
0
1
2
3
4
5
Two Way Time (seconds)
TERTIARY
UPPER CRETACEOUS
LOWER CRETACEOUS
Eider SS
LATE JURASSIC
Abenaki
Formation
EARLY JURASSIC
SALT
BASEMENT

Line EC 72-117 Courtesy of Geological Survey of Canada

Seismic section EC 72-117 and interpretation provided by Geological Survey of Canada. Additional interpretation by Department of Mines & Energy. See figure 7.1 for section location.

Whale and Horseshoe Basins	
Exploration Wells	13
Oil Shows	2
Oil & Gas Shows	2

Source Rock:

- Not Yet Identified

Possible Source Rocks:

- Verrill Canyon Formation
- Egret Member

Reservoirs:

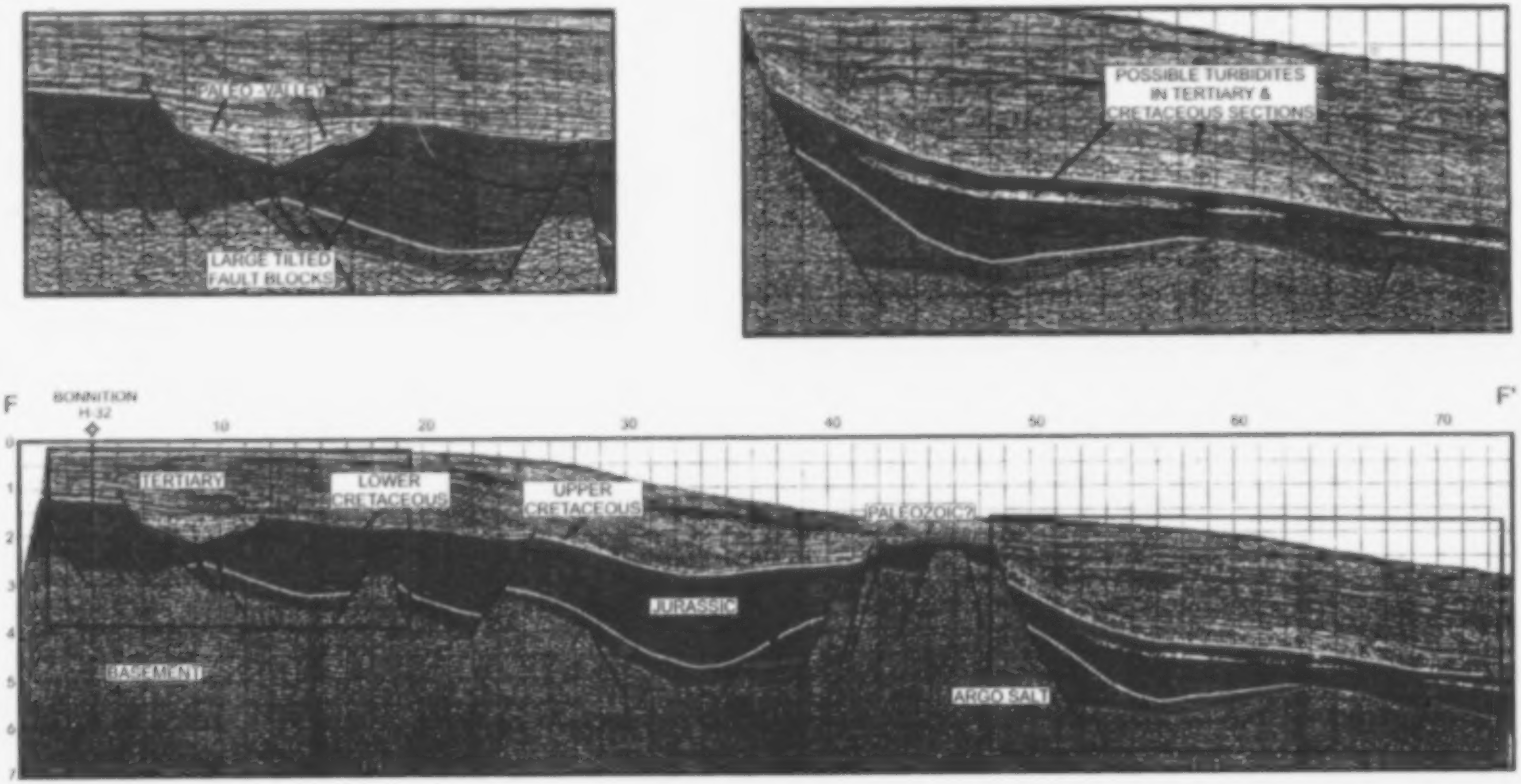
- Lower Tertiary Sandstones
- Logan Canyon Sandstones (Eider)
- Missisauga Sandstones
- Mimac Sandstones
- Abernaki Carbonate Bank
- Iroquois Carbonate

Play Concepts

- Subcrop of Jurassic reservoir rocks against Avalon unconformity where the Eider is also closed or not present
- Drape of the Eider sandstone over deeper structures
- Drape of Jurassic reservoirs, that are not breached by the Eider, over deeper structures
- Faulting against regional dip of Jurassic reservoir rocks
- Drape and stratigraphic pinchout of lower Teritary reservoirs

Table 7.2

Bonnition Basin Seismic Lines


PALEO-VALLEY
LARGE TILTED FAULT BLOCKS
POSSIBLE TURBIDITES IN TERTIARY & CRETACEOUS SECTIONS
F
F'
BONNITION H-32
10
20
30
40
50
60
70
0
1
2
3
4
5
6
7
TERTIARY
LOWER CRETACEOUS
UPPER CRETACEOUS
PALEOZOIC?
JURASSIC
BASEMENT
ARGO SALT

Bonnition Basin Seismic Section: This section shows the presence of a thick sequence of Jurassic and Cretaceous sediments with a number of possible trapping mechanisms including an Upper Cretaceous or Tertiary paleo-valley, titled fault blocks, and possible turbidites within the Tertiary and Lower Cretaceous sections. Interpreted line provided by GSC. Additional interpretation provided by Dept of Mines and Energy. See figure 7.1 for section location.

Figure 7.5

7.4 Southeast Grand Banks

The southeast Grand Banks includes the Carson/Bonnition and Flemish basins (in some texts the latter is referred to as the South Flemish Pass basin). Only four wells have been drilled in these basins, all of which were located along an elevated terrace running along on the northwest margin, that had a thinned Jurassic and Cretaceous section. The *Bonnition H-32* and *St. George J-55* wells encountered Lower Cretaceous and Jurassic sandstones, and *Bonnition* had gas shows in Lower Cretaceous Mississauga sands. Section FF' (figure 7.5) indicates that the Cretaceous and Jurassic sediments thicken considerably to the southeast of the terrace. Several play possibilities are evident including a large Upper Cretaceous or Lower Tertiary paleo-valley, that in addition to containing possible reservoirs, provides evidence of a river system that could have fed considerable quantities of sand into the area. Tilted Cretaceous fault blocks similar to those that created traps in Jeanne d'Arc Basin provided the trapping mechanism for most of the fields discovered to date. Additionally, broad continuous mounds within the Tertiary and Lower Cretaceous have been interpreted to be turbidites - which can be very large, laterally continuous and contain stacked reservoirs. A number of large fields discovered offshore West Africa, Gulf of Mexico and Brazil are located in turbidite reservoirs, but such features have not yet been actively pursued as exploration targets offshore Newfoundland or Labrador.

Carson /Bonnition /
South Flemish Pass Basins:

Exploration Wells	4
Gas Shows	1 (Mississauga Sandstone in Bonnition H-32)

Possible Source Rocks:

- Egret Member
- Verrill Canyon Shale equivalent

Reservoirs:

- Lower Cretaceous sandstones (Avalon/Ben Nevis and Hibernia equivalent)
- Jurassic sandstones (Jeanne d'Arc, Tempest, Voyager Equivalent)
- Jurassic carbonates (Iroquois)
- Sandstone fill within a Lower Tertiary or Upper Cretaceous paleo-valley
- Lower Tertiary and Lower Cretaceous turbidites

Play Concepts:

- Drape of Lower Cretaceous and Jurassic resevoirs over deep seated structures (basement faults, basement arches)
- Tilted fault blocks and horsts within the Cretaceous and Jurassic
- Stratigraphic subcrops against the base-of-Tertiary unconformity and pinchouts against basement-cored ridges
- Submarine fans and turbidites

Table 7.2

7.4 Southeast Grand Banks

The southeast Grand Banks includes the Carson/Bonnition and Flemish basins (in some texts the latter is referred to as the South Flemish Pass basin). Only four wells have been drilled in these basins, all of which were located along an elevated terrace running along on the northwest margin, that had a thinned Jurassic and Cretaceous section. The *Bonnition H-32* and *St. George J-55* wells encountered Lower Cretaceous and Jurassic sandstones, and *Bonnition* had gas shows in Lower Cretaceous Mississauga sands. Section FF' (figure 7.5) indicates that the Cretaceous and Jurassic sediments thicken considerably to the southeast of the terrace. Several play possibilities are evident including a large Upper Cretaceous or Lower Tertiary paleo-valley, that in addition to containing possible reservoirs, provides evidence of a river system that could have fed considerable quantities of sand into the area. Tilted Cretaceous fault blocks similar to those that created traps in Jeanne d'Arc Basin provided the trapping mechanism for most of the fields discovered to date. Additionally, broad continuous mounds within the Tertiary and Lower Cretaceous have been interpreted to be turbidites - which can be very large, laterally continuous and contain stacked reservoirs. A number of large fields discovered offshore West Africa, Gulf of Mexico and Brazil are located in turbidite reservoirs, but such features have not yet been actively pursued as exploration targets offshore Newfoundland or Labrador.

Carson / Bonnition /
South Flemish Pass Basins:

Exploration Wells	4
Gas Shows	1 (Mississauga Sandstone in Bonnition H-32)

Possible Source Rocks:

- Egret Member
- Verrill Canyon Shale equivalent

Reservoirs:

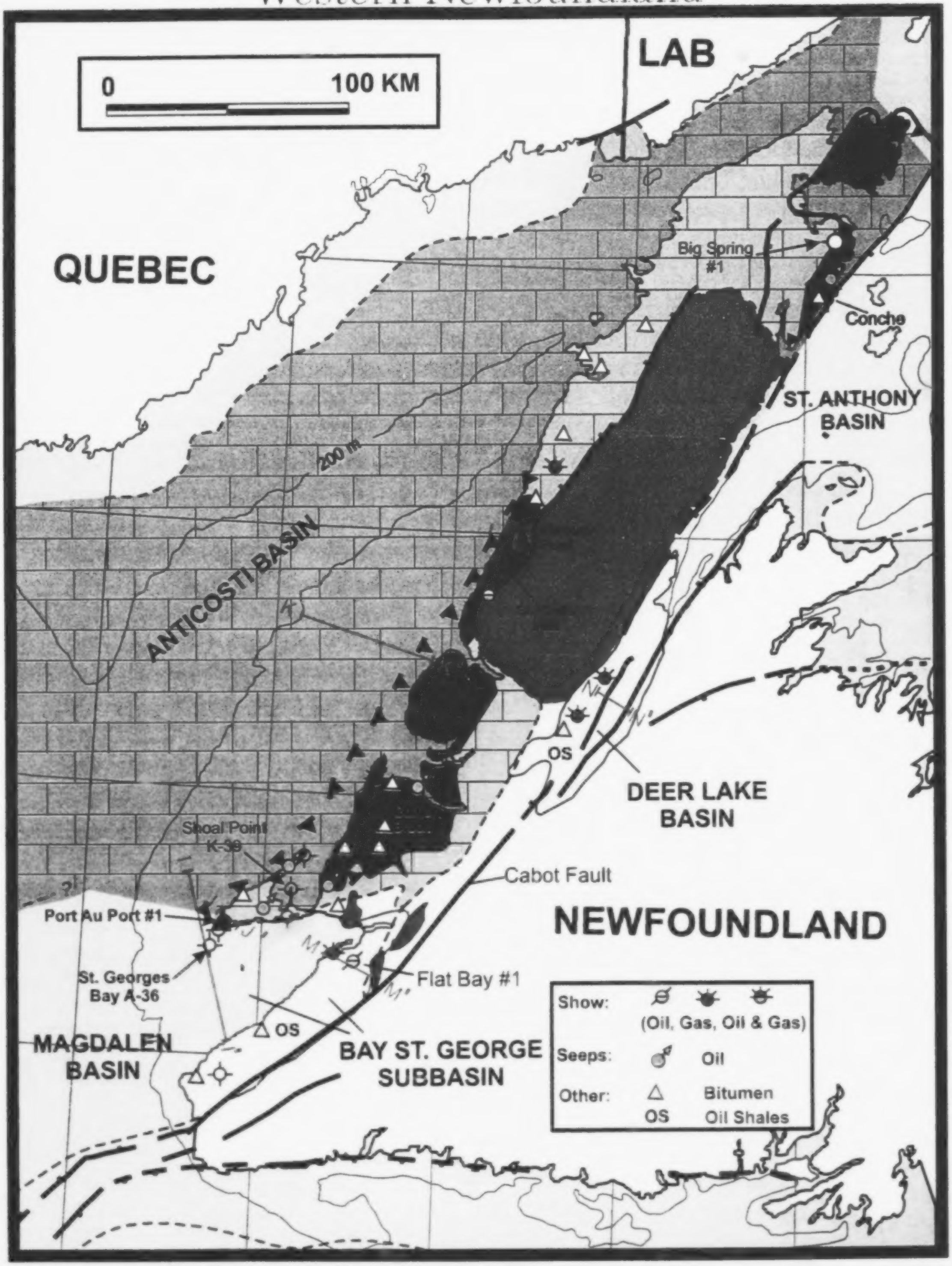
- Lower Cretaceous sandstones (Avalon/Ben Nevis and Hibernia equivalent)
- Jurassic sandstones (Jeanne d'Arc, Tempest, Voyager Equivalent)
- Jurassic carbonates (Iroquois)
- Sandstone fill within a Lower Tertiary or Upper Cretaceous paleo-valley
- Lower Tertiary and Lower Cretaceous turbidites

Play Concepts:

- Drape of Lower Cretaceous and Jurassic resevoirs over deep seated structures (basement faults, basement arches)
- Tilted fault blocks and horsts within the Cretaceous and Jurassic
- Stratigraphic subcrops against the base-of-Tertiary unconformity and pinchouts against basement-cored ridges
- Submarine fans and turbidites

Table 7.2

Western Newfoundland


LAB
0
100 KM
QUEBEC
Big Spring #1
Conche
ST. ANTHONY BASIN
200 m
ANTICOSTI BASIN
OS
DEER LAKE BASIN
Shoal Point K-39
Cabot Fault
Port Au Port #1
NEWFOUNDLAND
St. Georges Bay A-36
Flat Bay #1
OS
MAGDALEN BASIN
BAY ST. GEORGE SUBBASIN
Show:
(Oil, Gas, Oil & Gas)
Seeps: Oil
Other: △ Bitumen
OS Oil Shales

Geological map of western Newfoundland showing geological terranes, hydrocarbon shows and well locations.

Figure 8.1

Section 8 Western Newfoundland

Section 8.1

Introduction

As discussed in Section 2 (History of Exploration) about sixty old wells were drilled in western Newfoundland since the first exploratory well in 1867. These wells were concentrated in four areas - Parsons Pond, St. Paul's Inlet, the Deer Lake Basin and at Shoal Point on the Port Au Port Peninsula. The failure to make a commercial discovery can be reasonably explained by the following:
(1) None of the drilling locations were chosen with the help of any sort of geophysical survey and many were drilled with very little geological control or scientific analysis. Drilling locations were chosen largely on the basis of surface oil seeps.
(2) Most of the wells drilled were shallow (less than 700 metres) and only two exceeded 1000 metres, despite sediment thicknesses that typically exceed 3000 metres. Therefore, many of the deeper rock units, which may have the better hydrocarbon potential, were never penetrated.
(3) Most of the wells drilled were concentrated very close together (27 near Parsons Pond and 13 at Shoal Point) so only a small percentage of the prospective area was actually tested.

Much of the exploration to date, including many of the old wells drilled in the area, targeted the Lower Paleozoic strata of the Anticosti Basin, within foreland fold and thrust belt of the External Humber Zone (figure 3.1). Rocks within this terrane consist of essentially autochthonous to parautochthonous Cambrian to Middle Ordovician shelf and foreland basin strata along with allochthonous deepwater sediments of coeval age. These sediments are both overlain and onlapped by a Late Ordovician to Middle Devonian foreland basin succession (figure 8.2). The second prospective terrane is bounded within a number of Carboniferous wrench basins that straddle the Cabot Fault, including two basins (the Deer Lake Basin and Bay St. George Sub-basin) that are exposed onshore western Newfoundland.

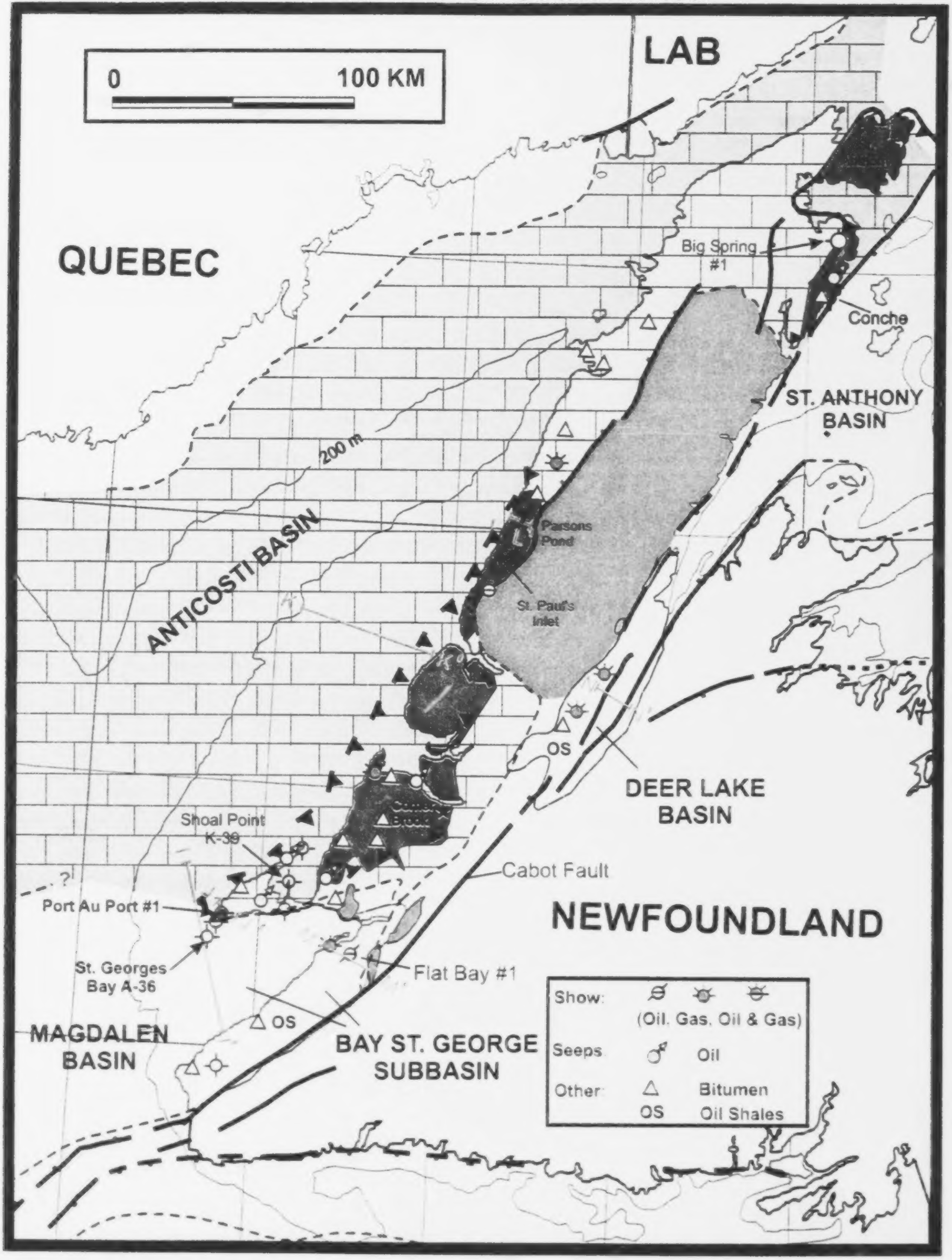
Over the past 25 years, stratigraphic and mapping studies by the Government of Newfoundland and Labrador Geological Survey and at Memorial University delineated a solid stratigraphic framework for western Newfoundland (figures 8.1 and 8.2) that has benefitted recent exploration. It was the structural studies of Stockmal and Waldron, however, that helped stimulate the latest phase of exploration. In 1990 Stockmal and Waldron proposed that the Cambro-Ordovician carbonates of the Port au Port Peninsula, which had been previously interpreted as autochthonous (non-transported), rather were allochthonous, carried by a major westward thrust into the Anticosti Basin. This movement was believed to have created a triangle zone that was exposed along the western shore of the peninsula. This hypothesis was primarily based on a re-interpretation of a couple of old, poor quality, seismic lines, but was proven to be largely correct by more recent seismic data (figure 8.3). During the early 1990's, large land positions were acquired by Mobil, Norcen, BHP and Hunt Oil, and about 5000 km of seismic data was acquired offshore western Newfoundland, along with about 800 kilometres onshore. Five deep wells were subsequently drilled in the Port au Port area, during the 1990's, that resulted in one discovery.

Western Newfoundland

Old Exploration Wells	60 (estimated)
Modern Exploration Wells	8 (Including: 5 deep wells in the Port au Port area; one one well that failed to reach its target and was abandoned at 700 metres; one well on the Great Northern Peninsula; and one shallow well in the Flat Bay area)
Significant Discoveries	1
Oil Shows:	Numerous in old wells and surface seeps
Gas Shows:	Numerous in old wells and in mining exploration holes

Table 8.1

Western Newfoundland


LAB
0
100 KM
QUEBEC
Big Spring #1
Conche
ST. ANTHONY BASIN
200 m
ANTICOSTI BASIN
Parsons Pond
St. Paul's Inlet
OS
DEER LAKE BASIN
Corner Brook
Shoal Point K-39
?
Port Au Port #1
Cabot Fault
NEWFOUNDLAND
St. Georges Bay A-36
Flat Bay #1
OS
MAGDALEN BASIN
BAY ST. GEORGE SUBBASIN
Show: (Oil, Gas, Oil & Gas)
Seeps: Oil
Other: △ Bitumen
OS Oil Shales

Geological map of western Newfoundland showing geological terranes, hydrocarbon shows and well locations.

Figure 8.1

Section 8 Western Newfoundland

Section 8.1

Introduction

As discussed in Section 2 (History of Exploration) about sixty old wells were drilled in western Newfoundland since the first exploratory well in 1867. These wells were concentrated in four areas - Parsons Pond, St. Paul's Inlet, the Deer Lake Basin and at Shoal Point on the Port Au Port Peninsula. The failure to make a commercial discovery can be reasonably explained by the following:
(1) None of the drilling locations were chosen with the help of any sort of geophysical survey and many were drilled with very little geological control or scientific analysis. Drilling locations were chosen largely on the basis of surface oil seeps.
(2) Most of the wells drilled were shallow (less than 700 metres) and only two exceeded 1000 metres, despite sediment thicknesses that typically exceed 3000 metres. Therefore, many of the deeper rock units, which may have the better hydrocarbon potential, were never penetrated.
(3) Most of the wells drilled were concentrated very close together (27 near Parsons Pond and 13 at Shoal Point) so only a small percentage of the prospective area was actually tested.

Much of the exploration to date, including many of the old wells drilled in the area, targeted the Lower Paleozoic strata of the Anticosti Basin, within foreland fold and thrust belt of the External Humber Zone (figure 3.1). Rocks within this terrane consist of essentially autochthonous to parautochthonous Cambrian to Middle Ordovician shelf and foreland basin strata along with allochthonous deepwater sediments of coeval age. These sediments are both overlain and onlapped by a Late Ordovician to Middle Devonian foreland basin succession (figure 8.2). The second prospective terrane is bounded within a number of Carboniferous wrench basins that straddle the Cabot Fault, including two basins (the Deer Lake Basin and Bay St. George Sub-basin) that are exposed onshore western Newfoundland.

Over the past 25 years, stratigraphic and mapping studies by the Government of Newfoundland and Labrador Geological Survey and at Memorial University delineated a solid stratigraphic framework for western Newfoundland (figures 8.1 and 8.2) that has benefitted recent exploration. It was the structural studies of Stockmal and Waldron, however, that helped stimulate the latest phase of exploration. In 1990 Stockmal and Waldron proposed that the Cambro-Ordovician carbonates of the Port au Port Peninsula, which had been previously interpreted as autochthonous (non-transported), rather were allochthonous, carried by a major westward thrust into the Anticosti Basin. This movement was believed to have created a triangle zone that was exposed along the western shore of the peninsula. This hypothesis was primarily based on a re-interpretation of a couple of old, poor quality, seismic lines, but was proven to be largely correct by more recent seismic data (figure 8.8). During the early 1990's, large land positions were acquired by Mobil, Norcen, BHP and Hunt Oil, and about 5000 km of seismic data was acquired offshore western Newfoundland, along with about 800 kilometres onshore. Five deep wells were subsequently drilled in the Port au Port area, during the 1990's, that resulted in one discovery.

Western Newfoundland

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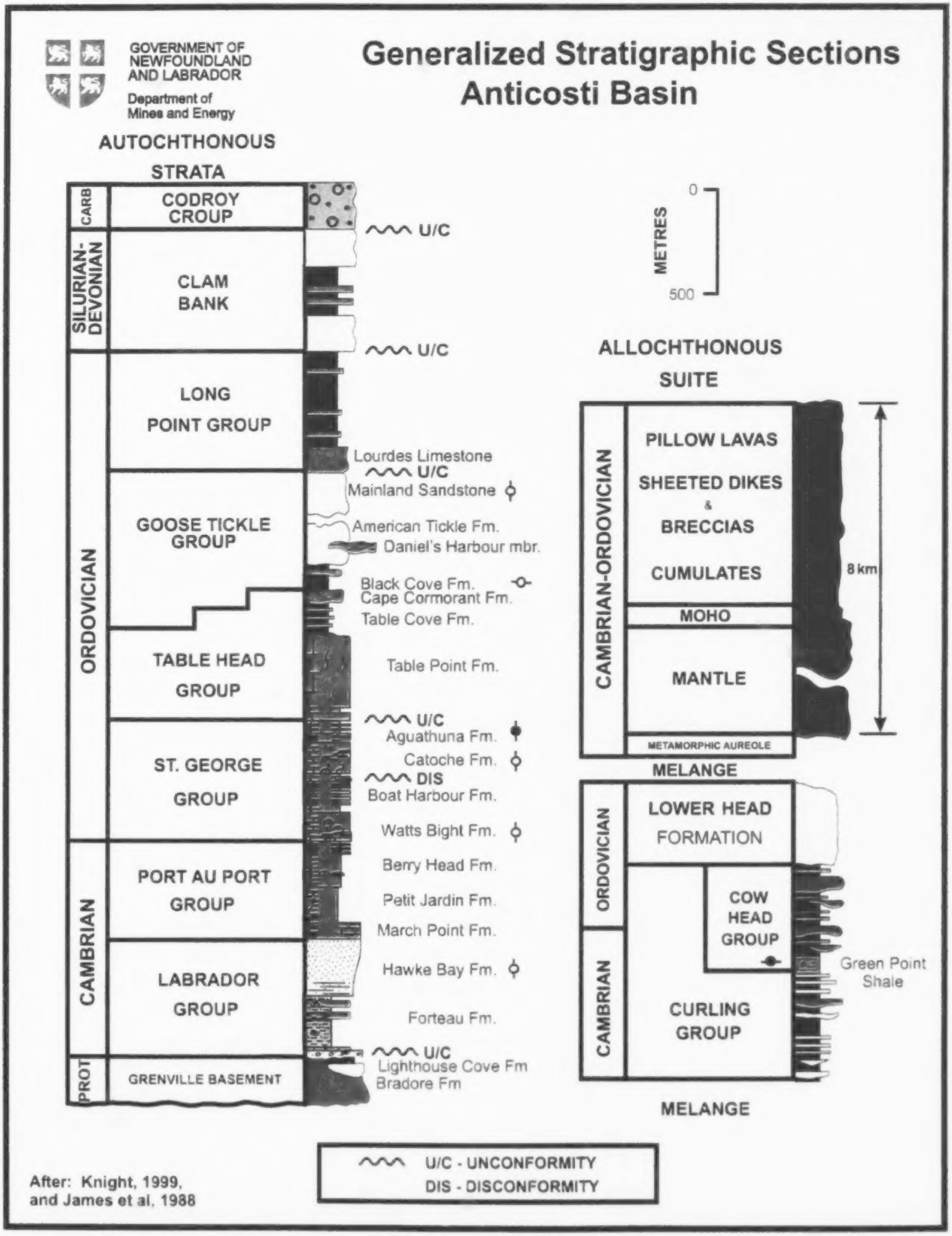
Significant Discoveries	1
Oil Shows:	Numerous in old wells and surface seeps
Gas Shows:	Numerous in old wells and in mining exploration holes

Table 8.1

Figure 8.2


GOVERNMENT OF NEWFOUNDLAND AND LABRADOR
Department of Mines and Energy
Generalized Stratigraphic Sections
Anticosti Basin
AUTOCHTHONOUS STRATA
CARB
CODROY GROUP
U/C
SILURIAN-DEVONIAN
CLAM BANK
U/C
ORDOVICIAN
LONG POINT GROUP
Lourdes Limestone
U/C
Mainland Sandstone
GOOSE TICKLE GROUP
American Tickle Fm.
Daniel's Harbour mbr.
Black Cove Fm.
Cape Cormorant Fm.
Table Cove Fm.
TABLE HEAD GROUP
Table Point Fm.
U/C
Aguathuna Fm.
ST. GEORGE GROUP
Catoche Fm.
DIS
Boat Harbour Fm.
Watts Bight Fm.
CAMBRIAN
PORT AU PORT GROUP
Berry Head Fm.
Petit Jardin Fm.
March Point Fm.
LABRADOR GROUP
Hawke Bay Fm.
Forteau Fm.
U/C
Lighthouse Cove Fm
Bradore Fm
PROT
GRENVILLE BASEMENT
METRES
0
500
ALLOCHTHONOUS SUITE
CAMBRIAN-ORDOVICIAN
PILLOW LAVAS
SHEETED DIKES
&
BRECCIAS
CUMULATES
MOHO
MANTLE
METAMORPHIC AUREOLE
8 km
MELANGE
ORDOVICIAN
LOWER HEAD FORMATION
COW HEAD GROUP
Green Point Shale
CAMBRIAN
CURLING GROUP
MELANGE
U/C - UNCONFORMITY
DIS - DISCONFORMITY

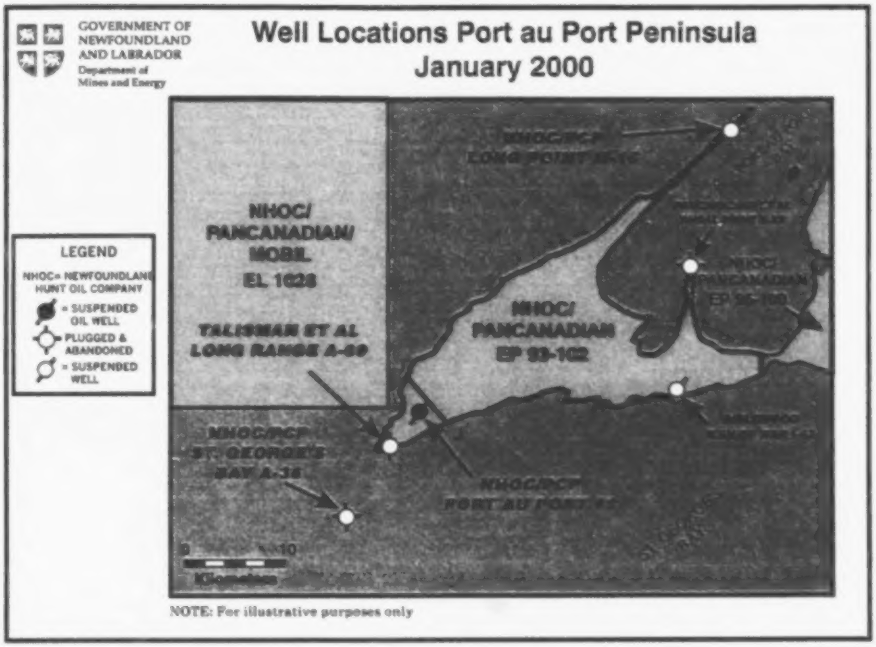
After: Knight, 1999, and James et al, 1988

Section 8.2

Port au Port Area

In 1994 Hunt Oil spudded *Port au Port #1(PAP#1)* which was the first well ever drilled in western Newfoundland based on seismic mapping (figure 8.3). The well encountered four zones of good porosity in the Cambro-Ordovician carbonate platform. The two lower zones were water-bearing but two upper zones, within the Aguathuna Formation, flowed oil at rates of 1528 and 1742 bopd (the two tested zones may be in communication). During an extended (9 day) test the pressure dropped off, indicating either a very limited reservoir or complicated geology near the wellbore. The fact that there were problems with paraffin buildup and salt plugging during the extended test, and that the reservoir had been invaded by more than 2200 barrels of drilling mud, may have also affected the test results. A new series of tests to determine the productive capacity of the well is currently being undertaken by Canadian Imperial Venture Corp, who later farmed into the project. Follow-up drilling at five other locations in the Port au Port area failed to provide new discoveries. (The Inglewood *Man of War I-42* well shown in figure 8.3 failed to reach its target depth and was abandoned at 700 metres).

Figure 8.3


GOVERNMENT OF NEWFOUNDLAND AND LABRADOR
Department of Mines and Energy
Well Locations Port au Port Peninsula
January 2000
LEGEND
NHOC= NEWFOUNDLAND HUNT OIL COMPANY
= SUSPENDED OIL WELL
PLUGGED & ABANDONED
= SUSPENDED WELL
NHOC/PCP
NHOC/ PANCANADIAN/ MOBIL
EL 1028
TALISMAN ET AL
LONG RANGE A-09
NHOC/ PANCANADIAN
EP 93-102
NHOC/ PANCANADIAN
NHOC/PCP
ST. GEORGE'S BAY A-36
NHOC/PCP
PORT AU PORT #1
0
10
Kilometres
NOTE: For illustrative purposes only

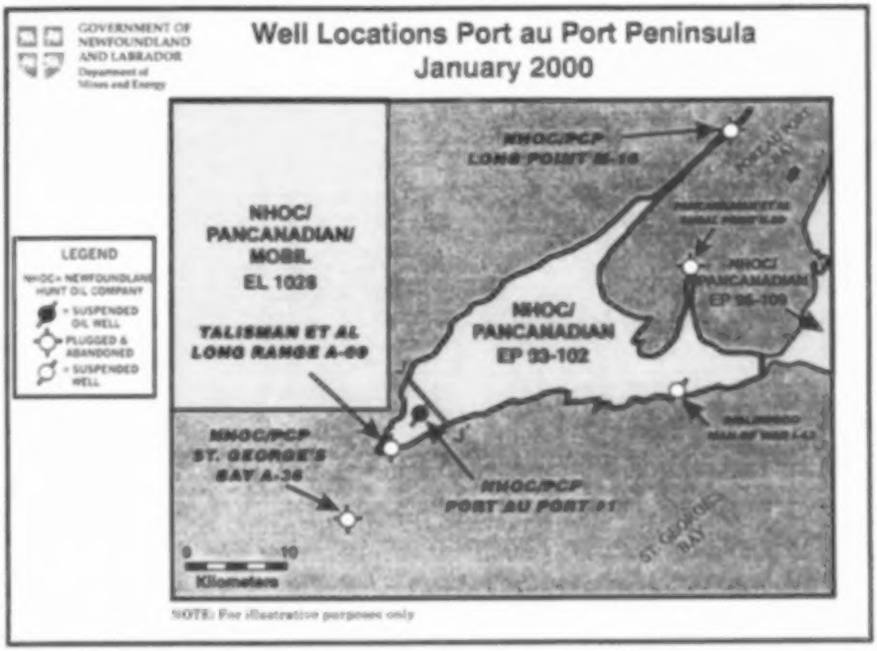
Released well information from four wells drilled during the 1990's indicates that all the carbonate reservoirs are within dolostones. The factors controlling porosity within the Aguathuna Formation (the productive zone in PAP#1) are not well understood and the porosity appears to be highly variable. However, deeper reservoirs, such as the Watt's Bight and Catoche Formations (which were water-bearing in PAP#1) may provide more regional and predictable dolostone targets. The PAP #1 well has proven the existence of a viable petroleum system within the deeper rocks of western Newfoundland. The oil in the well is high quality and sweet (51° API) and is consistent with a Cambro-Ordovician source. The recognized Cambro-Ordovician source rock in western Newfoundland is a shale within the Green Point Formation (figure 8.2).

Cross-section JJ' (figure 8.4) through PAP#1 (based on a Hunt Oil seismic line), illustrates that the structural mechanism is a footwall thrust. Figure 8.5 (cross-section II') is based on a seismic line through *St. George's Bay A-36*, that illustrates how the reverse faulting onshore gives way to a wrench fault-induced flower structure at the interface between the Carboniferous Bay St. George Subbasin and the Lower Paleozoic Anticosti Basin. The Carboniferous basins of western Newfoundland are known to have evolved in response to strike slip tectonics along the Cabot Fault. It is not known if the Cambro-Ordovician carbonate platform extends beneath the Bay St. George Carboniferous sediments (figure 8.5) because of poor seismic resolution below the Windsor Salt.

Section 8.2

Port au Port Area

Figure 8.3


GOVERNMENT OF NEWFOUNDLAND AND LABRADOR
Department of Mines and Energy
Well Locations Port au Port Peninsula
January 2000
LEGEND
NHOC= NEWFOUNDLAND HUNT OIL COMPANY
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PLUGGED & ABANDONED
= SUSPENDED WELL
NHOC/PCP
LONG POINT M-16
NHOC/ PANCANADIAN/ MOBIL
EL 1028
TALISMAN ET AL
LONG RANGE A-09
NHOC/ PANCANADIAN
EP 93-102
NHOC/ PANCANADIAN
EP 96-109
NHOC/PCP
ST. GEORGE'S BAY A-36
NHOC/PCP
PORT AU PORT #1
J
J'
PORT AU PORT BAY
ST. GEORGE'S BAY
0
10
Kilometers
NOTE: For illustrative purposes only

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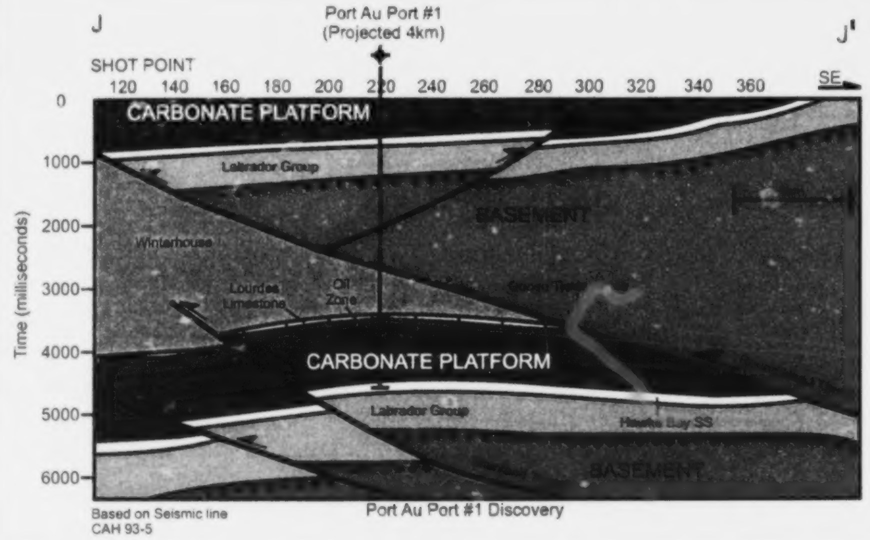
Figure 8.4


J
Port Au Port #1
(Projected 4km)
J'
SHOT POINT
120
140
160
180
200
220
240
260
280
300
320
340
360
SE
0
1000
2000
3000
4000
5000
6000
Time (milliseconds)
CARBONATE PLATFORM
Labrador Group
BASEMENT
Winterhouse
Lourdes Limestone
Oil Zone
CARBONATE PLATFORM
Labrador Group
Hawke Bay SS
BASEMENT
Based on Seismic line
CAH 93-5
Port Au Port #1 Discovery

Cross-section of the Port au Port #1 discovery: The Hunt/Pan Canadian Port au Port #1 well tested about 2000 bopd and 1.3 mmf/d of gas from a 15 metre net pay section within the Aguathuna Formation at the top of the carbonate platform. See figure 8.1 for section location.

Port au Port Area

Old Wells: 13 relatively shallow wells at Shoal Point
Modern Wells: 6
Significant Discoveries: 1

Source Rock: Green Point Formation shale

Possible Source Rocks: Black Cove Formation shale, and Carboniferous shales in the adjacent Bay St. George Subbasin

Reservoirs:

Within and beneath the Carbonate Bank

- Aguathuna Formation
- Catoche Formation
- Watts Bight Formation
- Hawke Bay Sandstone (Labrador Group)

Other:

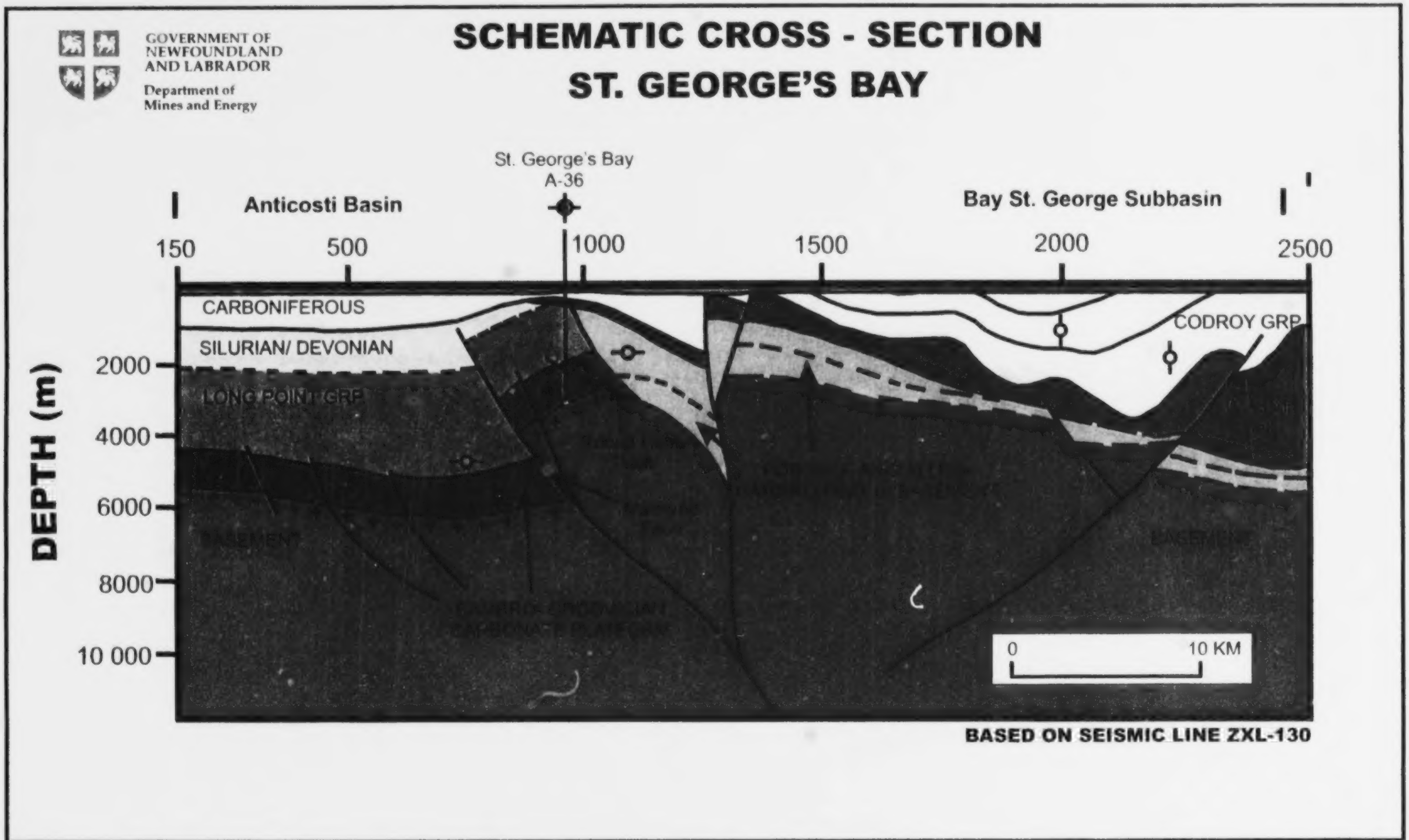
- Dolomitized carbonate conglomerates and calcarenites, and thin bedded massive turbidic sandstones within the Humber Arm allochthon
- Devonian / Silurian reefs (based on seismic anomalies)
- Possible sands within the flysch sequence and within the marginal marine sections of the Long Point and Clam Bank sequences of the foreland basin

Play Concepts: (Cambro-Ordovician)

- Thrusted sections of the carbonate platform (as per Port au Port #1)
- Horsts and tilted fault blocks of the carbonate platform within the foreland basin
- Stratigraphic traps: including Devonian/Silurian reefs and diagenetic porosity within carbonate bank

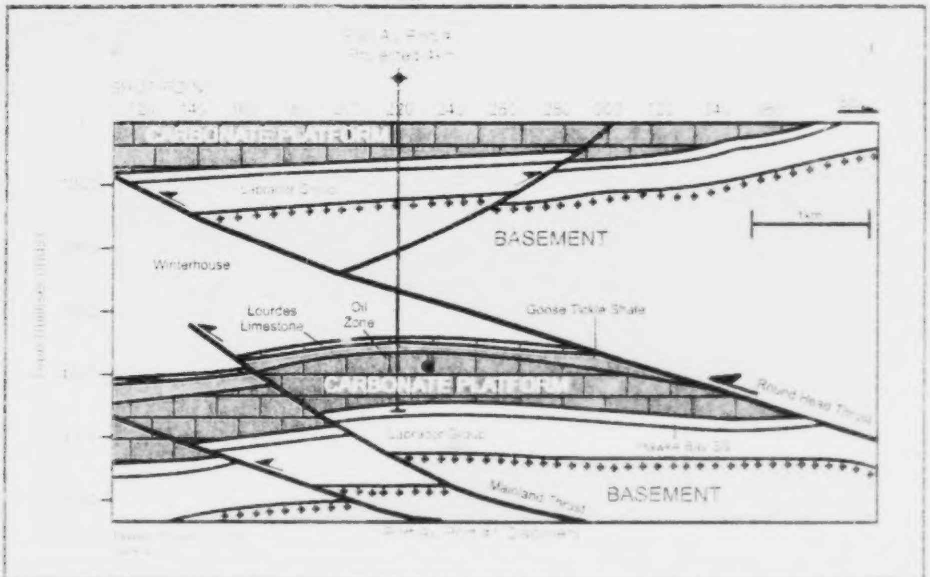
Table 8.2

Figure 8.5


GOVERNMENT OF
NEWFOUNDLAND
AND LABRADOR
Department of
Mines and Energy
SCHEMATIC CROSS - SECTION
ST. GEORGE'S BAY
St. George's Bay
A-36
Anticosti Basin
Bay St. George Subbasin
150
500
1000
1500
2000
2500
DEPTH (m)
2000
4000
6000
8000
10 000
CARBONIFEROUS
SILURIAN/ DEVONIAN
LONG POINT GRP
BASEMENT
CAMBRO-ORDOVICIAN
CARBONATE PLATFORM
CODROY GRP
BASEMENT
0
10 KM
BASED ON SEISMIC LINE ZXL-130

Seismic Line ZXL 130; located to the southwest of the Port au Port Peninsula, shows a flower structure at the interface of the Early Paleozoic Anticosti Basin and Carboniferous Bay St. George Subbasin, that was drilled by St. George's Bay A-36 in 1996. It is not known if the carbonate platform extends beneath the Carboniferous sediments in the Bay St. George Subbasin. See figure 8.1 for section location.

Figure 8.4


CARBONATE PLATFORM
Labrador Group
BASEMENT
1km
Winterhouse
Lourdes Limestone
Oil Zone
Goose Tickle Shale
CARBONATE PLATFORM
Round Head Thrust
Labrador Group
Hawke Bay SS
Mainland Thrust
BASEMENT

Cross-section of the Port au Port #1 discovery: The Hunt/Pan Canadian Port au Port #1 well tested about 2000 bopd and [illegible] of gas from a 15 metre net pay section within the Aguathuna Formation at the top of the carbonate platform. (See figure 8.[illegible] for section location)

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Play Concepts: (Cambro-Ordovician)

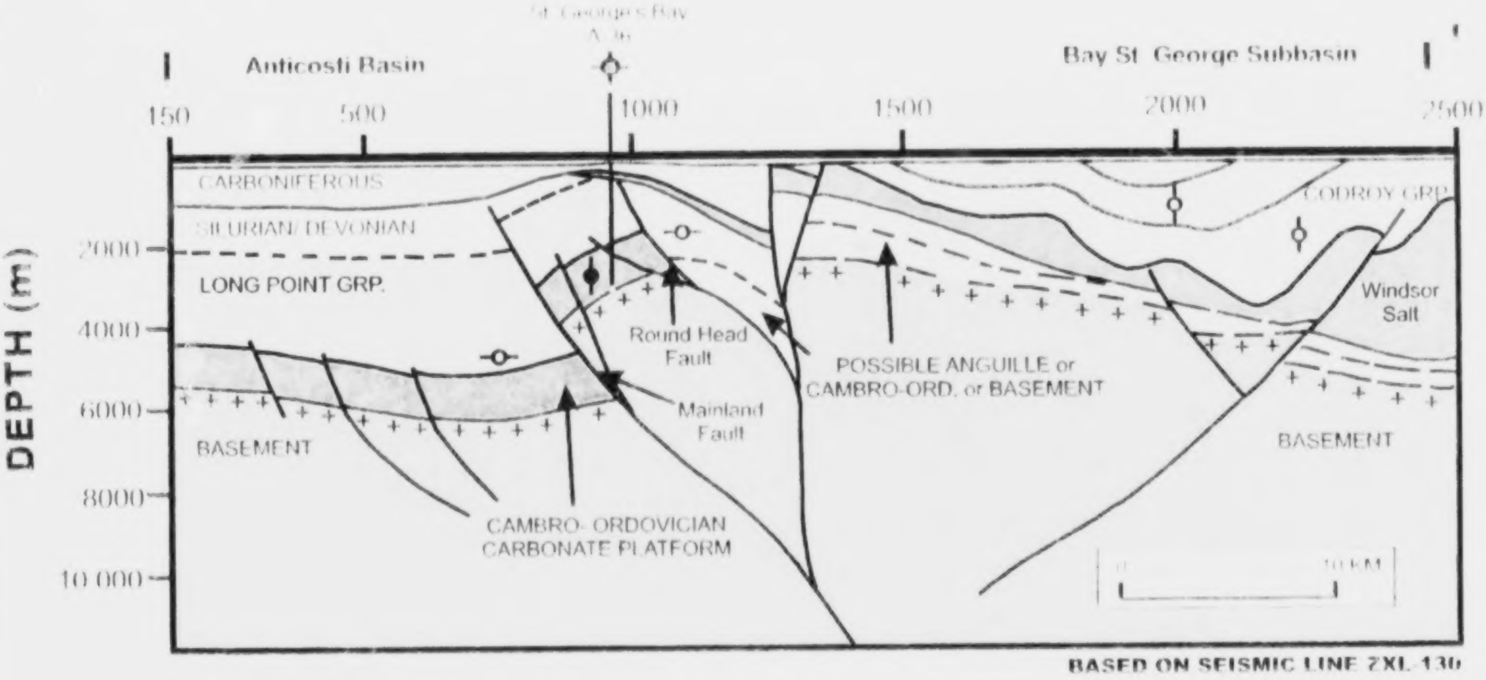
- Thrusted sections of the carbonate platform (as per Port au Port #1)
- Horsts and tilted fault blocks of the carbonate platform within the foreland basin
- Stratigraphic traps including Devonian-Silurian reefs and diagenetic porosity within carbonate bank

Table 8.2

Figure 8.5

GOVERNMENT OF
NEWFOUNDLAND
AND LABRADOR
Department of
Mines and Energy

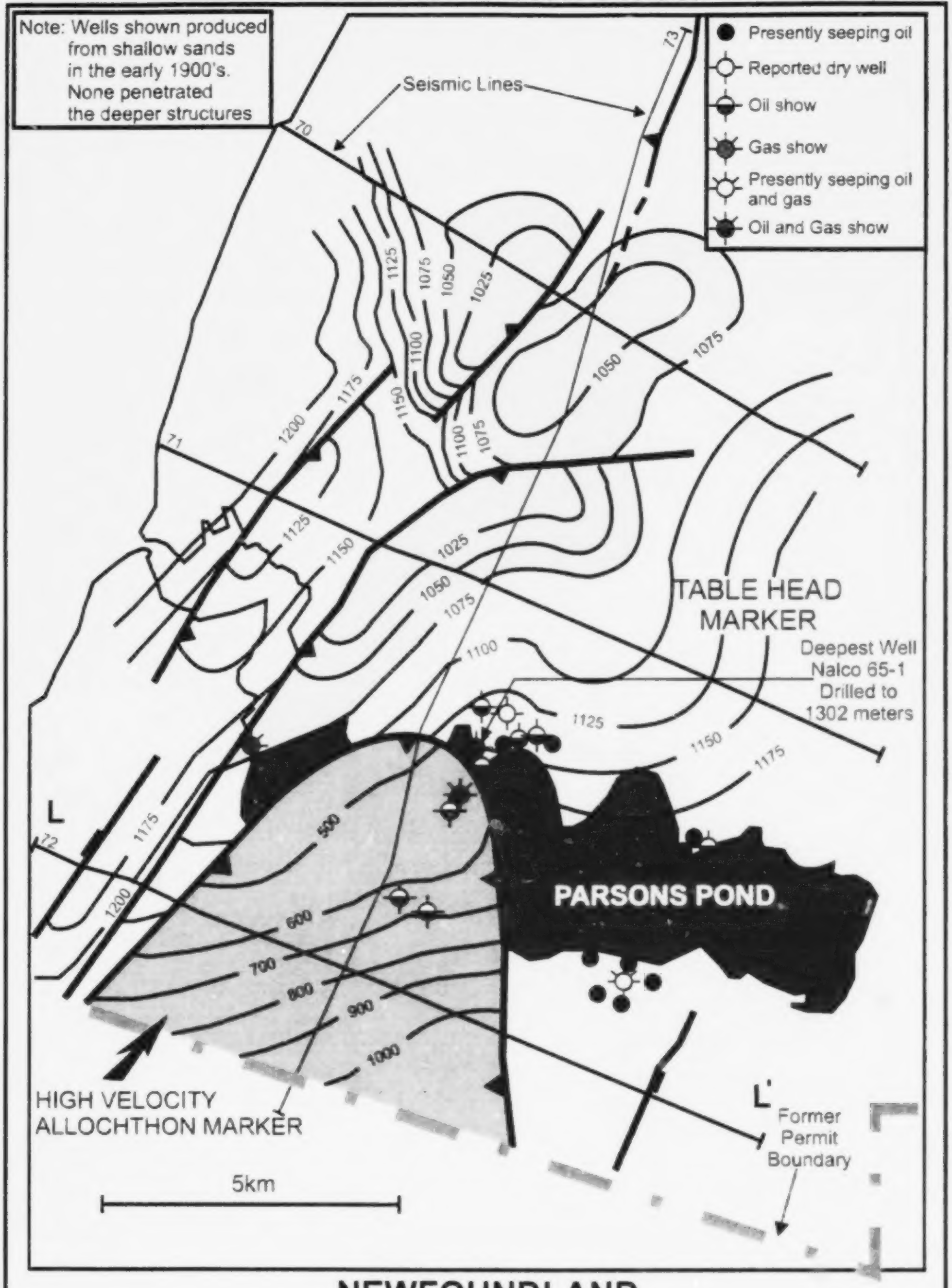
SCHEMATIC CROSS - SECTION
ST. GEORGE'S BAY


St. George's Bay
A-36
Anticosti Basin
Bay St. George Subbasin
150
500
1000
1500
2000
2500
DEPTH (m)
2000
4000
6000
8000
10 000
CARBONIFEROUS
SILURIAN/ DEVONIAN
LONG POINT GRP.
BASEMENT
Round Head
Fault
Mainland
Fault
CAMBRO- ORDOVICIAN
CARBONATE PLATFORM
POSSIBLE ANGUILLE or
CAMBRO-ORD. or BASEMENT
CODROY GRP
Windsor
Salt
BASEMENT
0
10 KM

BASED ON SEISMIC LINE ZXL-130

Seismic Line ZXL 130; located to the southwest of the Port au Port Peninsula, shows a flower structure at the interface of the Early Paleozoic Anticosti Basin and Carboniferous Bay St. George Subbasin, that was drilled by St. George's Bay A 36 in 1996. It is not known if the carbonate platform extends beneath the Carboniferous sediments in the Bay St. George Subbasin. See figure 8.1 for section location.

Parsons Pond Area


Note: Wells shown produced from shallow sands in the early 1900's. None penetrated the deeper structures
Seismic Lines
70
71
72
73
● Presently seeping oil
Reported dry well
Oil show
Gas show
Presently seeping oil and gas
Oil and Gas show
1125
1075
1050
1025
1100
1150
1175
1200
TABLE HEAD MARKER
Deepest Well Nalco 65-1 Drilled to 1302 meters
PARSONS POND
500
600
700
800
900
1000
L
L'
HIGH VELOCITY ALLOCHTHON MARKER
Former Permit Boundary
5km

NEWFOUNDLAND

PARSONS POND

TABLE HEAD/HVAM TIME STRUCTURE

Contours in Miliseconds

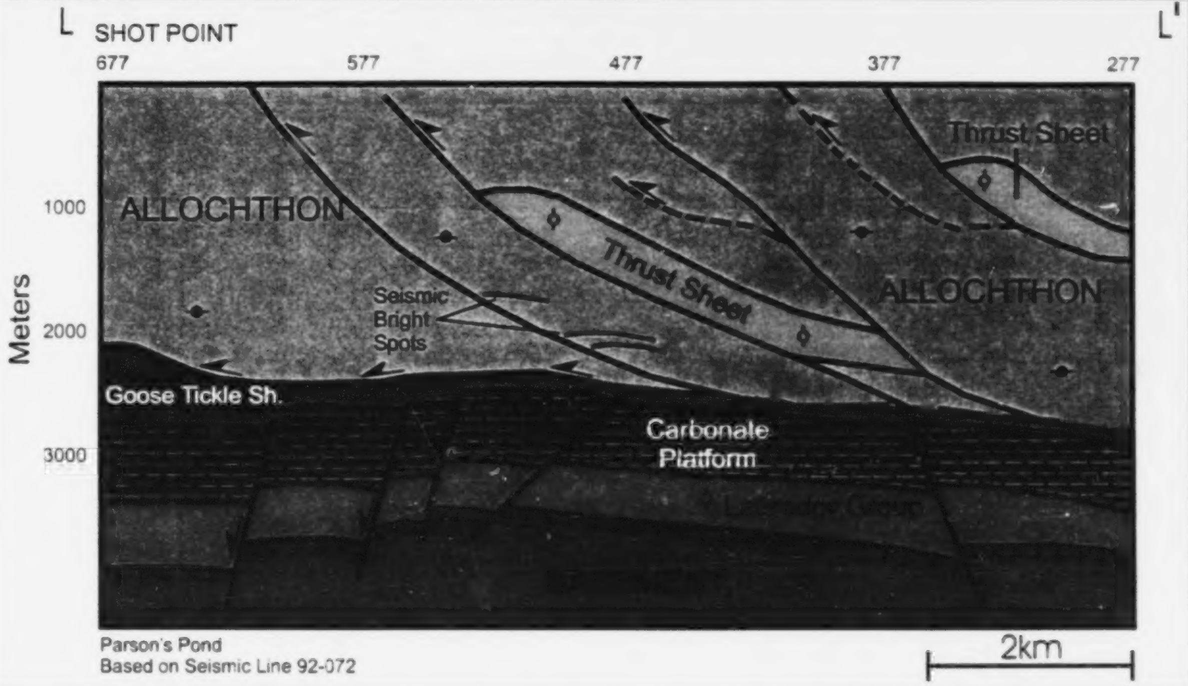
This time structure map prepared by Norcen, shows three closures at the top of the carbonate platform as well as a thrust slice within the allochthon, referred to here as the "High Velocity Allochthon Marker". None of these features have been penetrated by the wells shown.

Figure 8.6

Section 8.3

Parsons Pond Area

Figure 8.7



Parson's Pond
Based on Seismic Line 92-072

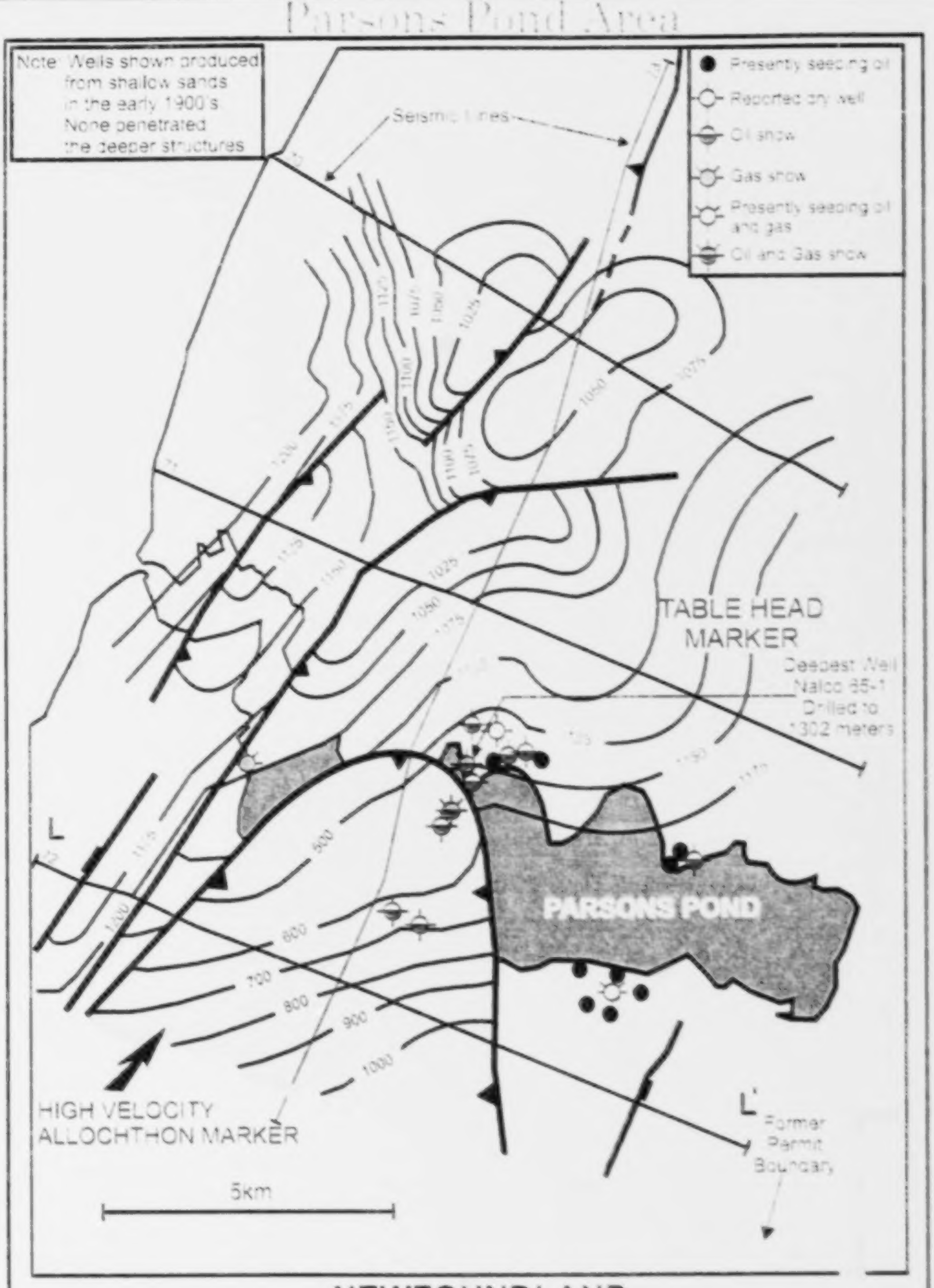
This section illustrates the structural style and possible traps at Parsons Pond. None of the wells drilled in the area were deep enough to test these structures. One well (NALCO 65-I) may have come close to penetrating the larger thrust sheet shown, but was abandoned when the cable tool bit was lost due to caving. The well "belched" gas for a month after it was abandoned. See figures 8.1 and 8.6 for section location.

Parsons Pond Area

Oil seeps were widely encountered throughout the Parsons Pond area in old wells and in community water wells. The area is characterized by an imbricated thrust stack of allochthonous Cow Head Group (including organic rich shales within the Green Point Formation) and Lower Head Formation turbidites, which overlies Cambro Ordovician shelf carbonates and flysch (figure 8.7). Both rock sequences have the potential to host hydrocarbon pools. Up to 40 metre thick sections of porous dolostone occur in the top of the Catoche Formation and locally at the base of the Table Point Formation. Near Port au Choix, 60 km to the north, these same dolostones hosted a, now-exhumed, oil field within a block faulted paleo-high (Baker and Knight, 1992). Structural plays within the shelf sequence are created by reverse and normal faults locally associated with rollover folds. These features could potentially be sourced from down dip areas where overlying Green Point Formation source rocks are juxtaposed with the carbonates.

Within the overlying imbricate thrust stack, seismic data have identified thrust sheet targets within the Cow Head Group and the Lower Head Formation (figure 8.7). Source rock shales of the

Parsons Pond Area


Note: Wells shown produced from shallow sands in the early 1900's. None penetrated the deeper structures
● Presently seeping oil
Reported dry well
Oil show
Gas show
Presently seeping oil and gas
Oil and Gas show
Seismic Lines
TABLE HEAD MARKER
Deepest Well Nalco 65-1 Drilled to 1302 meters
PARSONS POND
HIGH VELOCITY ALLOCHTHON MARKER
L
L'
Former Permit Boundary
5km
1125
1075
1150
1025
1100
1050
1200
1175
900
600
700
800
1000

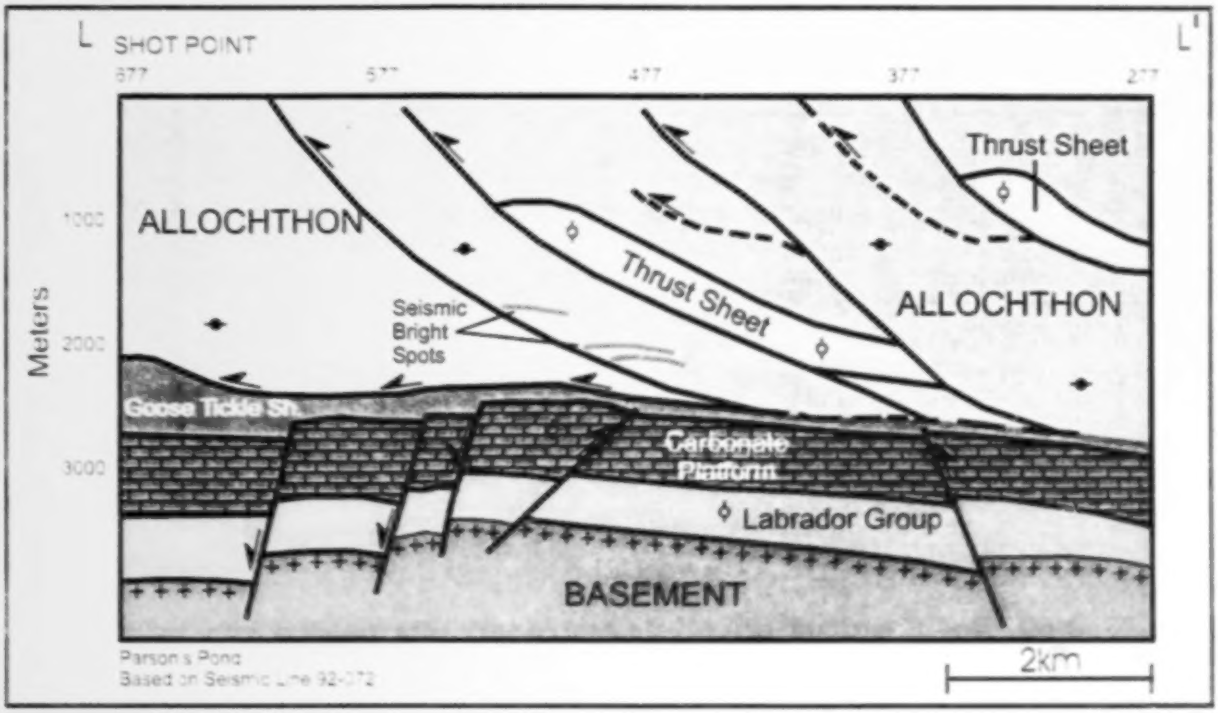
NEWFOUNDLAND
PARSONS POND
TABLE HEAD/HVAM TIME STRUCTURE

Contours in Miliseconds

This time structure map prepared by Norcen, shows three closures at the top of the carbonate platform as well as a thrust slice within the allochthon, referred to here as the "High Velocity Allochthon Marker." None of these features have been penetrated by the wells shown.

Figure 8.6

Figure 8.7


L
SHOT POINT
677
577
477
377
277
L'
1000
2000
3000
Meters
ALLOCHTHON
Thrust Sheet
Thrust Sheet
ALLOCHTHON
Seismic Bright Spots
Goose Tickle Sh.
Carbonate Platform
Labrador Group
BASEMENT
2km

Parson's Pond
Based on Seismic Line 92-072

This section illustrates the structural style and possible traps at Parsons Pond. None of the wells drilled in the area were deep enough to test these structures. One well (NALCO 65-I) may have come close to penetrating the larger thrust sheet shown, but was abandoned when the cable tool bit was lost due to caving. The well "belched" gas for a month after it was abandoned. See figures 8.1 and 8.6 for section location.

Parsons Pond Area

Oil seeps were widely encountered throughout the Parsons Pond area in old wells and in community water wells. The area is characterized by an imbricated thrust stack of allochthonous Cow Head Group (including organic rich shales within the Green Point Formation) and Lower Head Formation turbidites, which overlies Cambro-Ordovician shelf carbonates and flysch (figure 8.7). Both rock sequences have the potential to host hydrocarbon pools. Up to 40 metre thick sections of porous dolostone occur in the top of the Catoche Formation and locally at the base of the Table Point Formation. Near Port au Choix, 60 km to the north, these same dolostones hosted a now-exhumed, oil field within a block faulted paleo-high (Baker and Knight, 1992). Structural plays within the shelf sequence are created by reverse and normal faults locally associated with rollover folds. These features could potentially be sourced from down dip areas where overlying Green Point Formation source rocks are juxtaposed with the carbonates.

Within the overlying imbricate thrust stack, seismic data have identified thrust sheet targets within the Cow Head Group and the Lower Head Formation (figure 8.7). Source rock shales of the

Green Point Formation outcrop locally in the area and are expected at depth. Reservoirs may occur in dolomitized carbonate conglomerates and calcarenites carried in the hangingwall of thrusts. The thrust sheets shown in figure 8.3 could contain such reservoirs. Similar thrust-based carbonates are exposed at the Arches Provincial Park north of Parsons Pond where the limestone conglomerate and calcarenite has been replaced by a highly porous dolostone, that is also petroliferous. Alternatively, thick bedded massive turbidite sandstones of the Lower Head Formation may provide a suitable reservoirs. The presence of several horizontal bright spots in a number of thrust slices near Parsons Pond provide further evidence of the area's hydrocarbon potential.

A time structure map prepared by Norcen (figure 8.6) delineates undrilled prospects in the Parsons Pond area. The "high velocity allochthon marker" noted on the map is the larger thrust that is shown in cross-section LL' (figure 8.7). The other closures shown in figure 8.6 are mapped at the top of the carbonate platform. Although drilling records are incomplete, indications are that none of the old wells were deep enough to test the mapped structures. The 1965 NALCO well, drilled to 1302 metres, may have started to tag the edge of the larger thrust sheet shown in figure 8.7. The records report that the well "was abandoned at 1302 metres when considerable caving was encountered and the drill stem broken. Gas was encountered, with the best showing at 1302 metres. Belching could be heard for 9 - 12 metres from the well and continued for one month" (Petroleum Directorate, 1982). Given the size and number of structures identified, combined with the ubiquitous oil and gas shows, this area would be considered highly prospective for future exploration.

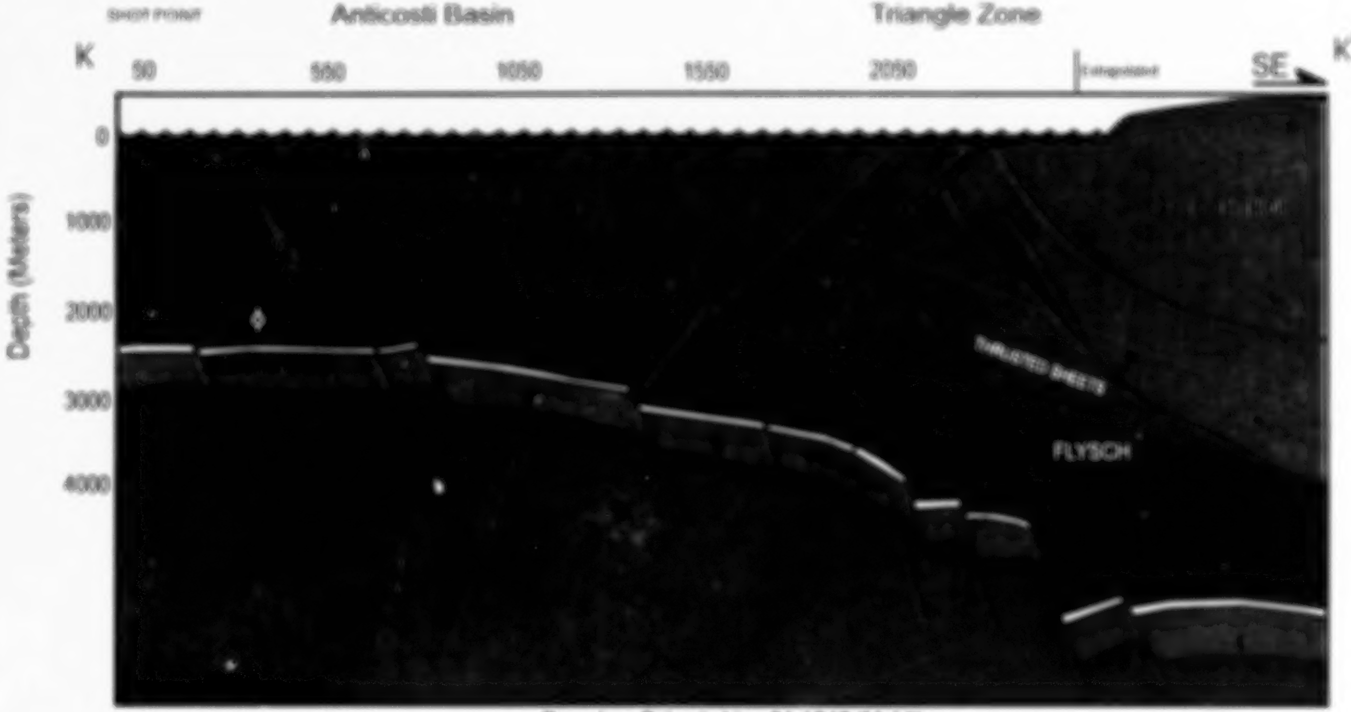
Oil Analysis of NALCO 65-1 Well

by Core Laboratories Canada Ltd., Calgary, Alberta, December, 1965

API @ 69°F	**43.4**
Sulphur wt.%	**0.26**
Viscosity S.U.S. @ 60°F	**52.4**
Viscosity S.U.S. @ 70°F	**49.5**
Viscosity S.U.S. @ 100°F	**43.0**
Pour Point	**20°F**
Salt Content lb NaCl/1000 Bbls	**14.3**
B. S. & W of Oil Layer	**Trace of H_2O**

Table 8.3

Triangle Zone Near Bonne Bay


SHOT POINT
Anticosli Basin
Triangle Zone
K
K'
SE
50
550
1050
1550
2050
Extrapolated
Depth (Meters)
0
1000
2000
3000
4000
THRUSTED SHEETS
FLYSCH

Based on Seismic Line 91-1547 (Mobil)

This offshore section, based on a Mobil seismic line located about 70km south of Parsons Pond, shows thrust sheets within the triangle zone as well as large block faults within the foreland basin to the west. None of these plays have yet been tested in Western Newfoundland. See figure 8.1 for section location.

Figure 8.8

Green Point Formation outcrop locally in the area and are expected at depth. Reservoirs may occur in dolomitized carbonate conglomerates and calcarenites carried in the hangingwall of thrusts. The thrust sheets shown in figure 8.3 could contain such reservoirs. Similar thrust-based carbonates are exposed at the Arches Provincial Park north of Parsons Pond where the limestone conglomerate and calcarenite have been replaced by a highly porous dolostone that is also petroliferous. Alternatively, thick bedded massive turbidite sandstones of the Lower Head Formation may provide a suitable reservoir. The presence of several horizontal bright spots in a number of thrust slices near Parsons Pond provide further evidence of the area's hydrocarbon potential.

A time structure map prepared by Nowlan (figure 8.6) delineates undrilled prospects in the Parsons Pond area. The "high velocity [illegible] marker" noted on the map is the larger thrust that is shown in cross-section LL' (figure 8.7). The other closures shown in figure 8.6 are mapped at the top of the carbonate platform. Although drilling records are incomplete, indications are that none of the old wells were deep enough to test the mapped structures. The 1965 NALCO well, drilled to 1302 metres may have started to tag the edge of the larger thrust sheet shown in figure 8.7. The records say that the well "was abandoned at 1302 metres when considerable caving was encountered and the drill stem broken. Gas was encountered, with the best showing at 1302 metres. Bubbling could be heard for 30 metres from the well and continued for one month" (Petroleum Directorate, 1982). Given the size and number of structures identified, combined with the ubiquitous oil and gas shows, this area would be considered highly prospective for future exploration.

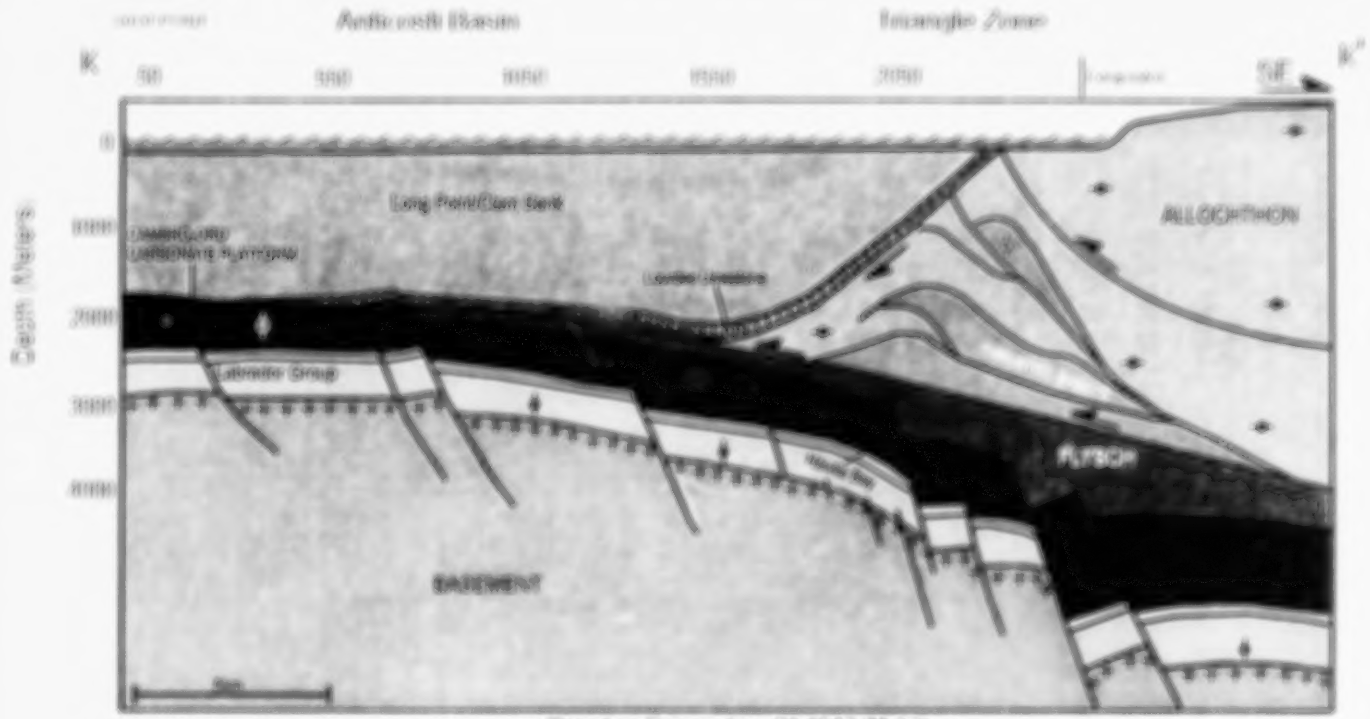
Oil Analysis of NALCO 65-1 Well

by Core Laboratories Canada Ltd., Calgary, Alberta, December, 1965

API @ 60°F	43.4
Sulphur wt.%	0.26
Viscosity S.U.S. @ 60°F	52.4
Viscosity S.U.S. @ 70°F	49.5
Viscosity S.U.S. @ 100°F	43.0
Pour Point	20°F
Salt Content lb NaCl/1000 Bbls	14.3
B. S. & W. of Oil Layer	Trace of H_2O

Table 8.3

Triangle Zone Near Bonne Bay


Anticosti Basin
Triangle Zone
K
K'
SE
500
1000
1500
2000
Depth (Meters)
0
1000
2000
3000
4000
Long Point/Clam Bank
Carbonate Platform
Lourdes Limestone
Labrador Group
BASEMENT?
ALLOCHTHON
FLYSCH

Based on Seismic Line 91-1587 (88-84)

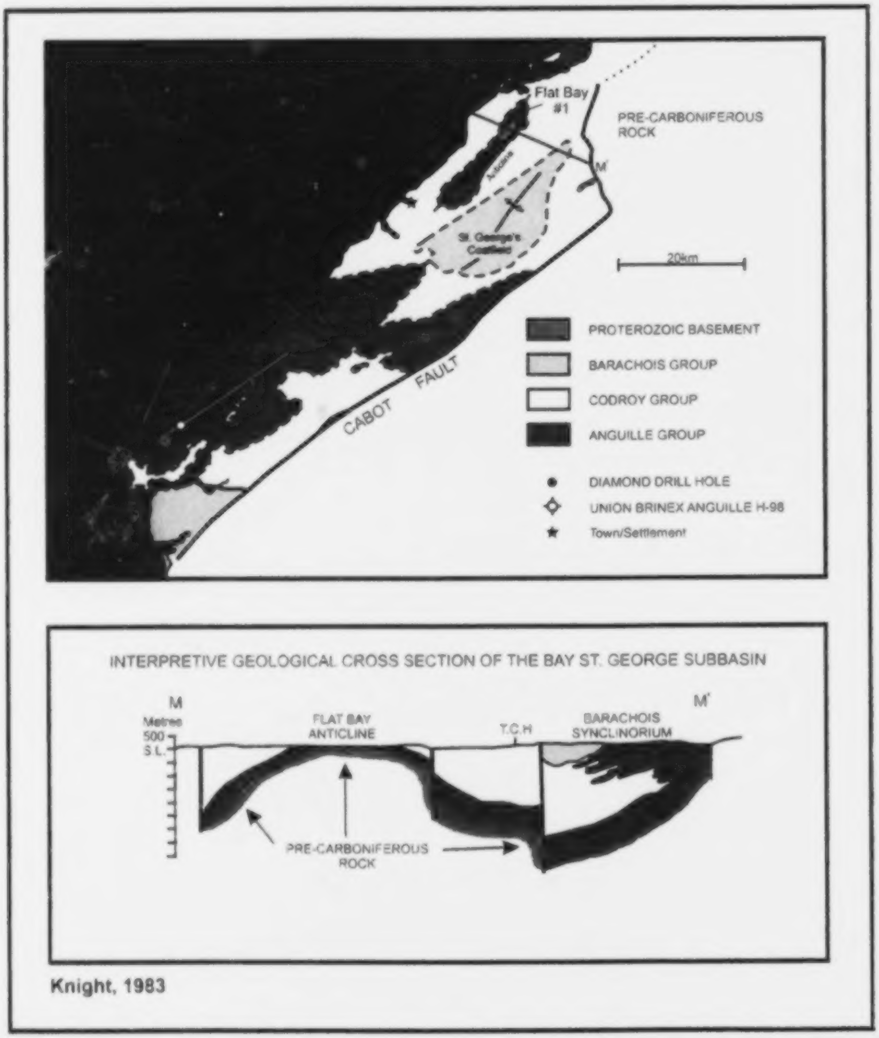
This offshore section, based on a Mobil seismic line located about 70km south of Parsons Pond, shows thrust sheets within the triangle zone as well as large block faults within the foreland basin to the west. None of these plays have yet been tested in Western Newfoundland. See figure 8.1 for section location.

Figure 8.8

Section 8.4
Bay St. George Subbasin

This Carboniferous basin has had a number of notable gas shows during extensive drilling for gypsum in the late 1950's (McKillop 1957). Most recently a live oil zone noted by McKillop was confirmed by a shallow exploration well drilled by Vulcan Minerals in 1999 that encountered live oil over a 100 metre interval (Vulcan Minerals press release - September 1999). One deep well (*Anguille H-98*) was drilled to 2311 metres in 1973 in a highly structured zone and encountered only traces of poor porosity. Seismic surveys and bedrock mapping suggest that Bay St. George subbasin is a collage of grabens, half grabens and horsts of various ages with sedimentary thickness locally of more than 5 km (figure 8.5, 8.9 and 8.10).

Figure 8.9


Flat Bay #1
PRE-CARBONIFEROUS ROCK
M'
Anticline
St. George's Coalfield
20km
CABOT FAULT
PROTEROZOIC BASEMENT
BARACHOIS GROUP
CODROY GROUP
ANGUILLE GROUP
DIAMOND DRILL HOLE
UNION BRINEX ANGUILLE H-98
Town/Settlement
INTERPRETIVE GEOLOGICAL CROSS SECTION OF THE BAY ST. GEORGE SUBBASIN
M
M'
Metres
500
S.L.
FLAT BAY ANTICLINE
T.C.H
BARACHOIS SYNCLINORIUM
PRE-CARBONIFEROUS ROCK

Knight, 1983

Simplified geological map and cross-section through the onland part of the Bay St. George Subbasin (modified after Knight, 1983).

Excellent marine and nonmarine sandstone reservoirs occur, especially in the north of the basin. Carbonate reefs (within the Codroy Road Formation) with high interskeletal porosity which outcrop at Ship Cove (figure 8.10), and on the north shore of the Port au Port Peninsula are expected to be present at depth. Salt diapirs are known from gravity and seismic surveys. Black shales developed in and below a basal evaporitic sequence in the Codroy Group as well as black deepwater lacustrine shales in the Anguille Group may provide suitable source rocks. Wrench faulting has produced large northeasterly trending folds and flower structures with significant fault offsets. A major wrench fault appears to run close to the coastline of St Georges Bay where it separates the onshore structure (figure 8.9) from the structure seen beneath the bay itself (figure 8.5).

Bay St. George Area Subbasin

Exploration Wells: 2 (Flat Bay #1 & Anguille H-98)
Oil Shows: 3 (in shallow drill holes)
Gas Shows: Several in old mining exploration holes

Source Rocks:

- Snake's Bight Shales
- Blanche Brook Coal Beds

Reservoirs:

- Sandstones of the Codroy an Anguille Groups
- Algal laminites, dolomites and biohermal limestones of the Codroy Group
- Possibly carbonate platform preserved beneath the Carboniferous.

Play Concepts

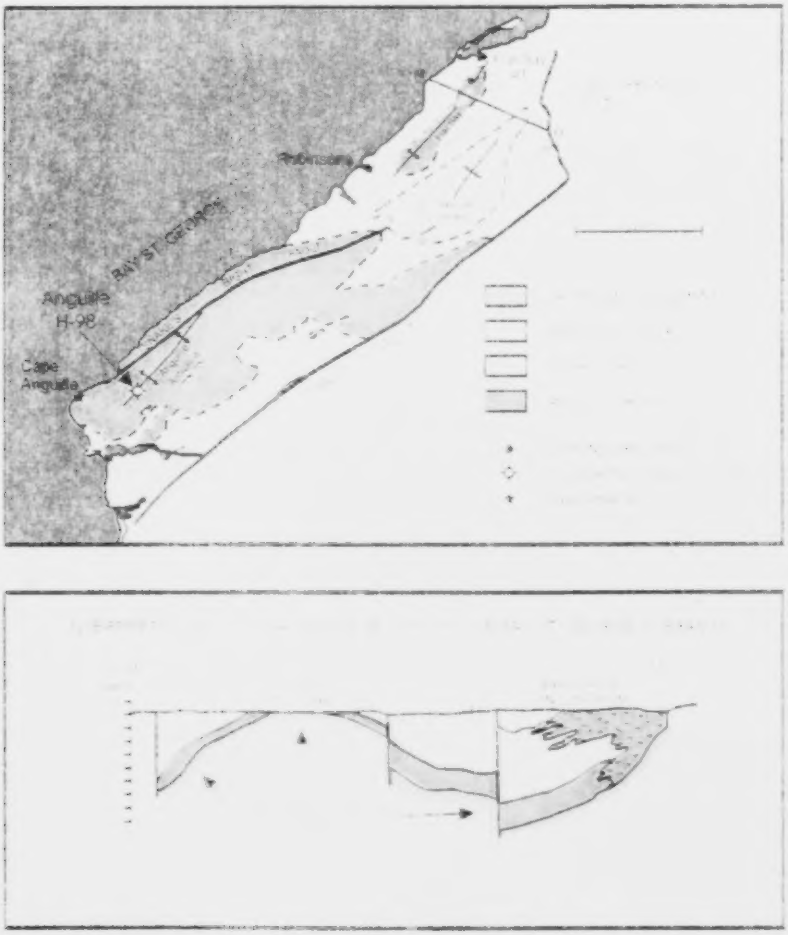
- Pinchout of Anguille and Codroy sandstones against the Flat Bay Anticline
- Drape of sands over salt swells
- Pinchouts against salt diapirs
- Flower structures and folds produced by wrench faulting
- Faulting within the Codroy and Anguille Groups
- Reefal buildups in Codroy Road formation overlain by Windsor evaporites. The exposed part of such a reef at Ship Cove is 10 to 15 metres high and 200 metres in width and exhibits high interskeletal porosity (Knight, pers. comm.) Similar reefal buildups are observed to occur on the north shore of the Port au Port Peninsula in the stratigraphic equivalent of the Ship Cove formation.

Table 8.4

[illegible]

[illegible] possible [illegible] during [illegible] gypsum in the late 1950's (McK[illegible]). More recently [illegible] noted by McK[illegible] confirmed [illegible] Mineral[illegible] in 1984 that [illegible] a 100 metre interval [illegible] (September 1989). One deep well [illegible] was drilled to 23[illegible] metres [illegible] fractured zone and encountered only [illegible] porosity. Seismic surveys [illegible] suggest that Bay St George subbasin [illegible] grabens that [illegible] sedimentary thickness [illegible] (figure 8.8, 8.9 and 8.10).

Figure 8.9



Knight, 1983

Simplified geological map and cross-section through the onland part of the Bay St. George Subbasin (modified after Knight, 1983 [illegible] marine and nonmarine sandstone reservoirs occur, especially in the north of the basin. Carbonate reefs within the Codroy Road Formation with high interskeletal porosity which outcrop at Ship Cove (figure 8.10) and on the north shore of the Port au Port Peninsula are expected to be present at depth. Salt diapirs are known from gravity and seismic surveys. Black shales developed in and below a basal evaporite sequence in the Codroy Group as well as the deepwater lacustrine shales in the Anguille Group may provide suitable source rocks. Wrench faulting has produced large, northeasterly trending folds and flower structures with significant fault offsets. A major wrench fault appears to run close to the coastline of St. Georges Bay where it separates the onshore structure (figure 8.9) from the structures seen beneath the bay itself (figure 8.5).

Bay St. George Area Subbasin

Exploration Wells:	2 (Flat Bay #1 & Anguille H-98)
Oil Shows:	3 (in shallow drill holes)
Gas Shows:	Several in old mining exploration holes

Source Rocks:
- Snake's Bight Shales
- Blanche Brook Coal Beds

Reservoirs:
- Sandstones of the Codroy an Anguille Groups
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Play Concepts
- Pinchout of Anguille and Codroy sandstones against the Flat Bay Anticline
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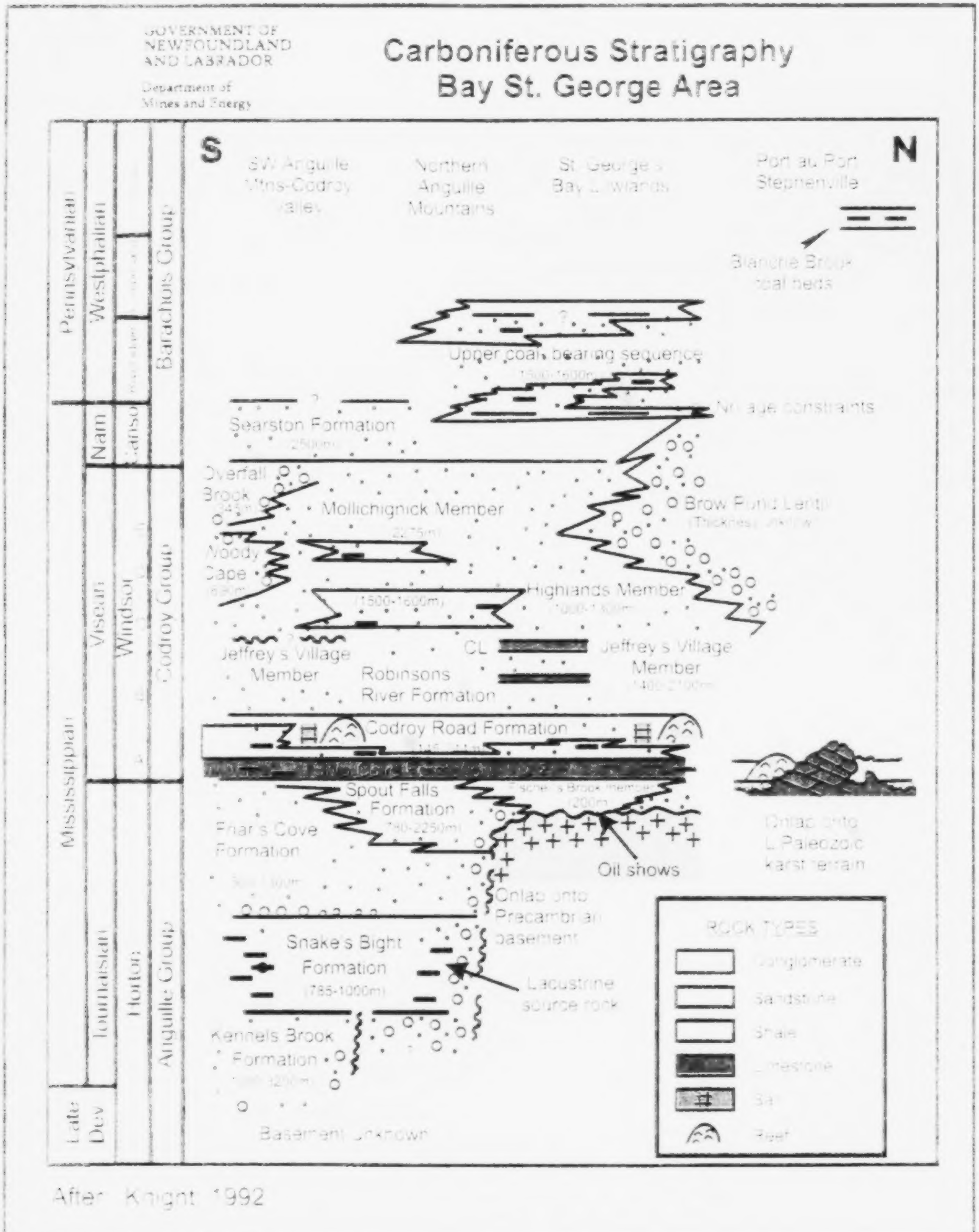
Table 3.4

Bay St. George Area Stratigraphic Chart

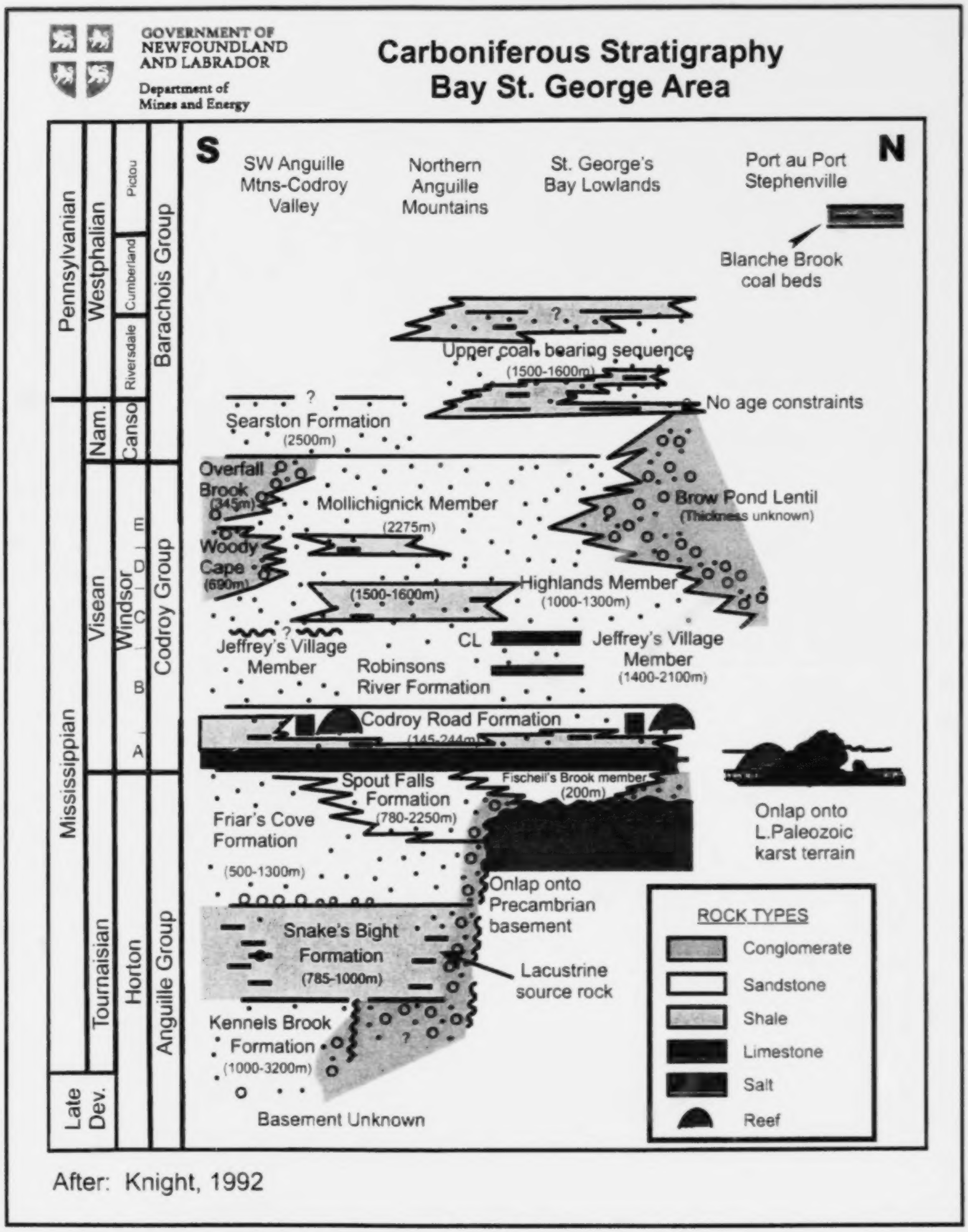

GOVERNMENT OF NEWFOUNDLAND AND LABRADOR
Department of Mines and Energy
Carboniferous Stratigraphy
Bay St. George Area
S
N
SW Anguille Mtns-Codroy Valley
Northern Anguille Mountains
St. George's Bay Lowlands
Port au Port Stephenville
Blanche Brook coal beds
Upper coal bearing sequence
(1500-1600m)
No age constraints
Searston Formation
(2500m)
Overfall Brook
(345m)
Mollichignick Member
(2275m)
Brow Pond Lentil
(Thickness unknown)
Woody Cape
(630m)
(1500-1600m)
Highlands Member
CL
Jeffrey's Village Member
Robinsons River Formation
Jeffrey's Village Member
Codroy Road Formation
Spout Falls Formation
(780-2250m)
Fischell's Brook member
(200m)
Friar's Cove Formation
Oil shows
Onlap onto L.Paleozoic karst terrain
Onlap onto Precambrian basement
Snake's Bight Formation
(785-1000m)
Lacustrine source rock
Kennels Brook Formation
Basement unknown
ROCK TYPES
Conglomerate
Sandstone
Shale
Limestone
Salt
Reef
Pennsylvanian
Mississippian
Late Dev
Westphalian
Nam
Visean
Tournaisian
Canso
Windsor
Horton
Barachois Group
Codroy Group
Anguille Group

After Knight 1992

Lithostratigraphy of the Bay St. George Sub-basin

Figure 8.10

Bay St. George Area Stratigraphic Chart


GOVERNMENT OF NEWFOUNDLAND AND LABRADOR
Department of Mines and Energy
Carboniferous Stratigraphy
Bay St. George Area
S
N
SW Anguille Mtns-Codroy Valley
Northern Anguille Mountains
St. George's Bay Lowlands
Port au Port Stephenville
Pennsylvanian
Westphalian
Pictou
Cumberland
Riversdale
Barachois Group
Nam.
Canso
Mississippian
Visean
Windsor
E
D
C
B
A
Codroy Group
Tournaisian
Horton
Anguille Group
Late Dev.
Blanche Brook coal beds
?
Upper coal bearing sequence
(1500-1600m)
No age constraints
?
Searston Formation
(2500m)
Overfall Brook
(345m)
Mollichignick Member
(2275m)
Brow Pond Lentil
(Thickness unknown)
Woody Cape
(690m)
(1500-1600m)
Highlands Member
(1000-1300m)
?
Jeffrey's Village Member
CL
Robinsons River Formation
Jeffrey's Village Member
(1400-2100m)
Codroy Road Formation
(145-244m)
Spout Falls Formation
(780-2250m)
Fischell's Brook member
(200m)
Friar's Cove Formation
(500-1300m)
Onlap onto L.Paleozoic karst terrain
Onlap onto Precambrian basement
Snake's Bight Formation
(785-1000m)
Lacustrine source rock
Kennels Brook Formation
(1000-3200m)
?
Basement Unknown
ROCK TYPES
Conglomerate
Sandstone
Shale
Limestone
Salt
Reef

After: Knight, 1992

Lithostratigraphy of the Bay St. George Sub-basin

Figure 8.10

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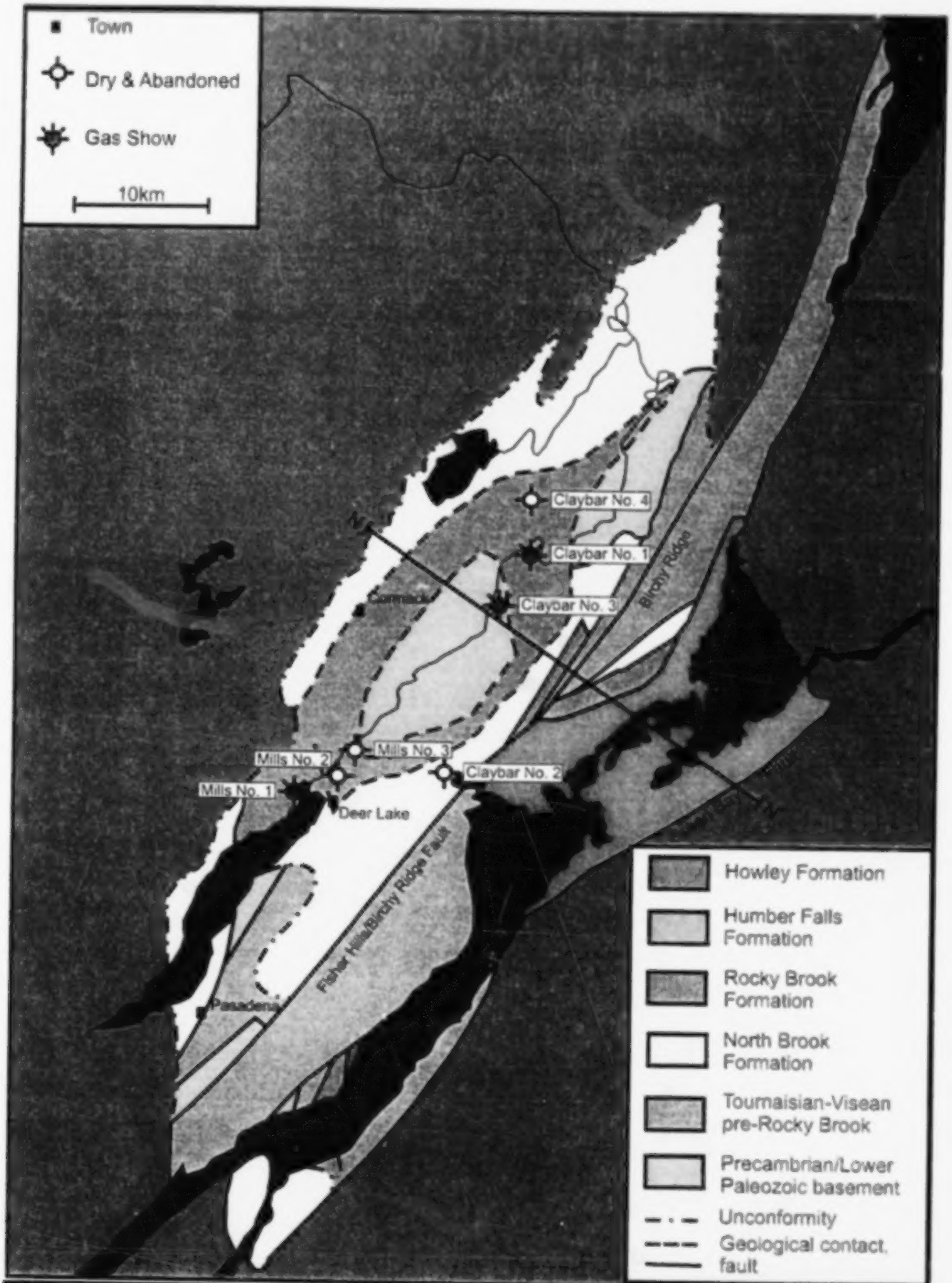
Deer Lake Basin


Town
Dry & Abandoned
Gas Show
10km
Claybar No. 4
Claybar No. 1
Claybar No. 3
Claybar No. 2
Mills No. 1
Mills No. 2
Mills No. 3
Cormack
Deer Lake
Pasadena
Birchy Ridge
Fisher Hills/Birchy Ridge Fault
N
N
Howley Formation
Humber Falls Formation
Rocky Brook Formation
North Brook Formation
Tournaisian-Visean pre-Rocky Brook
Precambrian/Lower Paleozoic basement
Unconformity
Geological contact, fault

Simplified geological map of the Deer Lake Basin showing the location of wells, all of which were drilled prior to 1960.

Figure 8.11

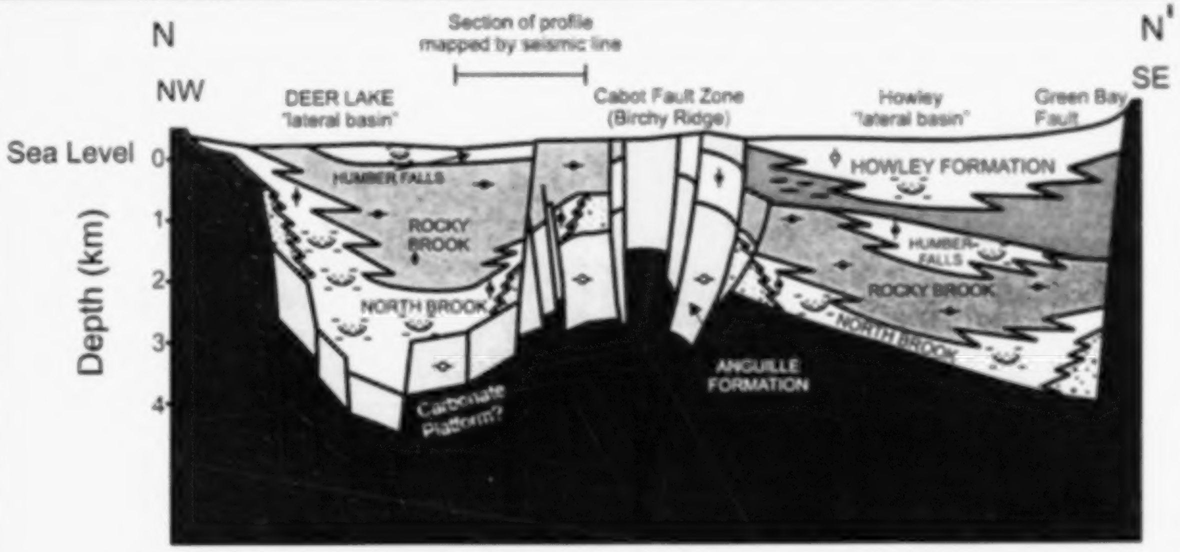
Section 8.5
Deer Lake Basin

Deer Lake Basin

The Deer Lake Basin is the site of seven old exploration wells drilled in the early and mid 1900's (figure 8.11) one of which (*Mill's #1*) was a gas blow out that caught fire and destroyed the rig. Gas still bubbles from the well today. Of the four Claybar wells drilled, two flowed significant gas to surface. Flow rates were not measured.

The basin contains predominantly non-marine sediments which include alluvial fan, braided and meandering river, lacustrine and swamp deposits that were laid down in a strike slip structural setting. Syntectonic uplifts along the axis of the basin have partitioned it into a series of interconnected depocentres, and created a number of potential drilling targets (see figure 8.12). The early exploration efforts demonstrated the oil and gas generative capacity of the organic rich Rocky Brook shales and the reservoir quality of the North Brook sandstones. Given that the well locations were chosen without the benefit of seismic data it is unlikely that they were drilled in optimal locations. In the late 1990's seismic data was acquired in the basin (most of which is still proprietary).

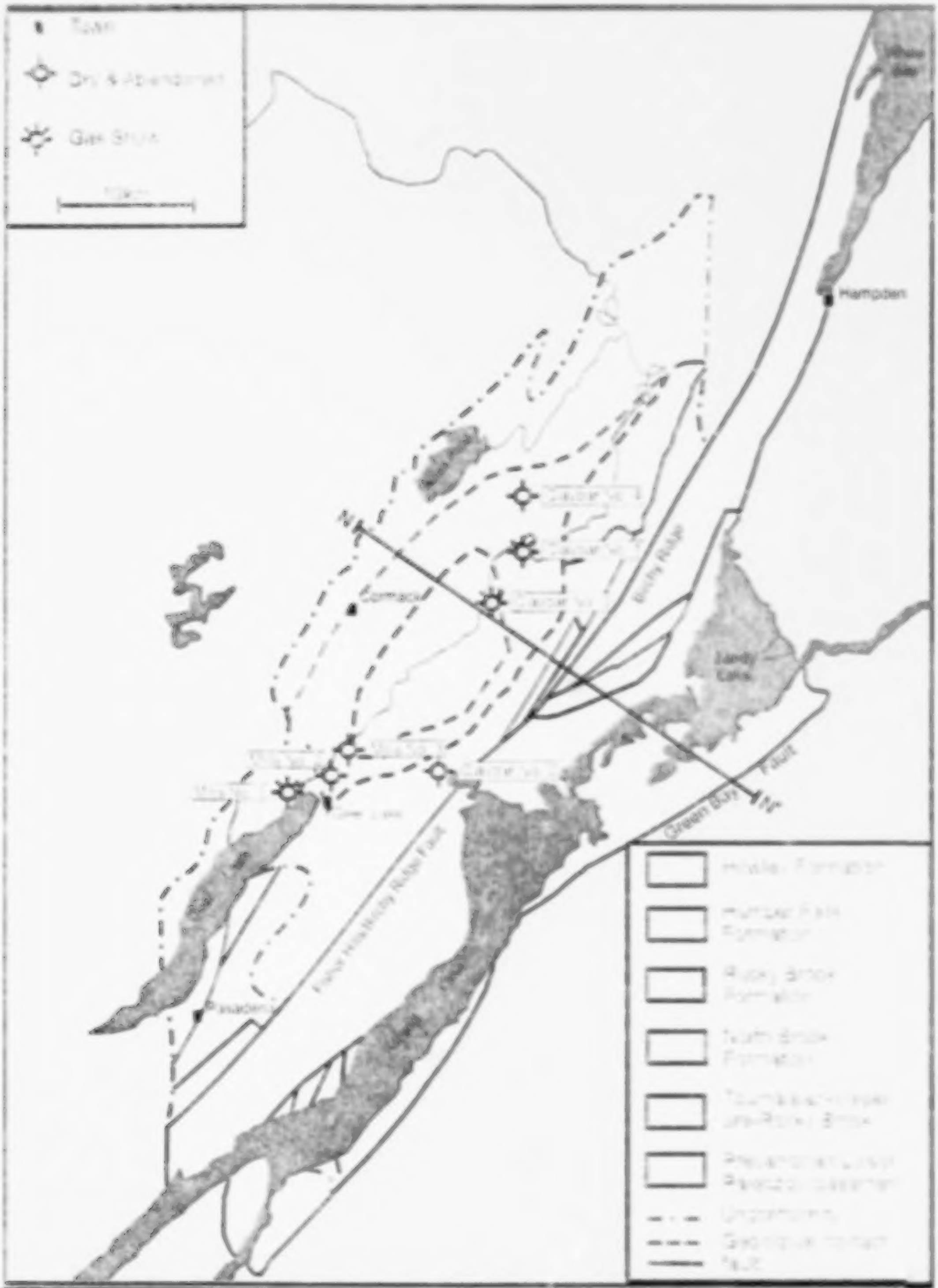
Figure 8.12


N
Section of profile mapped by seismic line
N'
NW
DEER LAKE "lateral basin"
Cabot Fault Zone (Birchy Ridge)
Howley "lateral basin"
Green Bay Fault
SE
Sea Level
0
1
2
3
4
Depth (km)
HUMBER FALLS
ROCKY BROOK
NORTH BROOK
Carbonate Platform?
HOWLEY FORMATION
HUMBER-FALLS
ROCKY BROOK
NORTH BROOK
ANGUILLE FORMATION

Modified after Hamblin et al. (1995)

Section NN' illustrates the structural style and possible petroleum plays, of the Deer Lake Basin. This section is, for the most part, based on surface geology and gravity and magnetic data, with a short section to the west of the Birchy Ridge based on released seismic data. See figure 8.11 for section location.

Deer Lake Basin


Town
Dry & Abandoned
Gas Show
10km
Hampden
Cormack
Pasadena
Sandy Lake
Birchy Ridge
Green Bay Fault
Fisher Hills/Birchy Ridge Fault
N
N'
Howley Formation
Humber Falls Formation
Rocky Brook Formation
North Brook Formation
Tournaisian-Lower pre-Rocky Brook
Precambrian-Lower Paleozoic basement
Unconformity
Geological contact
Fault

Simplified geological map of the Deer Lake Basin showing the location of wells all of which were drilled prior to 1960

Figure 8.11

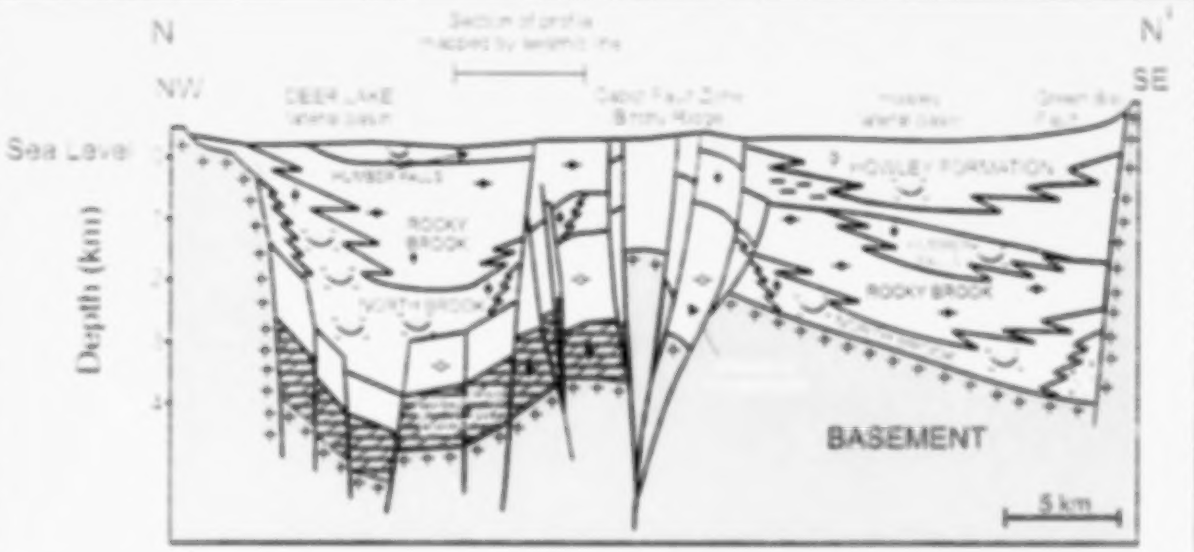
Section 8
Deer Lake Basin

Deer Lake Basin

The Deer Lake Basin is the site of seven oil exploration wells drilled in the early and mid 1900's (figure 8.11) one of which (Mull's #1) was a gas blow out that caught fire and destroyed the rig. Gas still bubbles from the well today. Of the four Claybar wells drilled, two flowed significant gas to surface. Flow rates were not measured.

The basin contains predominantly non-marine sediments which include alluvial fan, braided and meandering river, lacustrine and swamp deposits that were laid down in a strike slip structural setting. Synsedimentary faults along the axis of the basin have partitioned it into a series of interconnected depocentres, and created a number of potential drilling targets (see figure 8.12). The early exploration efforts demonstrated the oil and gas generative capacity of the organic rich Rocky Brook shales and the reservoir quality of the North Brook sandstones. Given that the well locations were chosen without the benefit of seismic data it is unlikely that they were drilled in optimal locations. In the late 1990's seismic data was acquired in the basin (most of which is still proprietary).

Figure 8.12


N
N'
NW
SE
Section of profile mapped by seismic line
DEER LAKE lateral basin
Cabot Fault Zone Birchy Ridge
Howley lateral basin
Green Bay Fault
Sea Level
Depth (km)
0
1
2
3
4
HUMBER FALLS
ROCKY BROOK
NORTH BROOK
HOWLEY FORMATION
ROCKY BROOK
BASEMENT
5 km

Modified after Hamblin et al. (1995)

Section NN' illustrates the structural style and possible petroleum plays of the Deer Lake Basin. This section is, for the most part, based on surface geology and gravity and magnetic data, with a short section to the west of the Birchy Ridge based on released seismic data. See figure 8.11 for section location.

Deer Lake Basin
Exploration Wells

- *7 early wells*
- Gas shows: 3 significant flows to surface

Source Rock:

- Rocky Brook Shales

Reservoirs:

- North Brook sandstones and conglomerates (porosities ranging from 12-18%)

Possible Reservoirs

- Sandstone and conglomerates within the Humber Falls and Howley formations
- Ordovician Carbonate Platform beneath the Carboniferous. It is not yet known if reservoir quality carbonates exist below the Carboniferous cover.

Play Concepts

- Anticline features and fault traps
- Pinchouts and channel sandstones in the North Brook Formation
- Alluvial fan pinchouts against basin margins and Birchy Ridge
- Faulting of the Ordovician Carbonate platform (if preserved and porous) beneath the Carboniferous

Table 8.5

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RELATED WEB LINKS

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City of St.John's	www.city.st-johns.nf.ca
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Capital Coast	www.entnet.nf.ca/capital-coast
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Education and Training

Memorial University	www.mun.ca
Marine Institute	www.ifmt.nf.ca
College of the North Atlantic	www.northatlantic.nf.ca
Centre for Cold Ocean Resources Engineering	www.mun.ca/research/publications/centres/ccore.html
Institute for Marine Dynamics	www.mun.ca/recruit/virtour/imd.html

Boards, Organizations and Companies

Canada Newfoundland Offshore Petroleum Board	www.cnopb.nfnet.com
Newfoundland Offshore Industries Association	www.noia.nf.ca
Terra Nova Project	www.terranoveproject.com
Hibernia Management Development Corp	www.hibernia.ca
GSC Basins Site	http://agc.bio.ns.ca/BASINS/

APPENDIX A

WELLS PER BASIN BY YEAR

Wells Per Basin Per Year

	Year (Spud Date)																																		
Basin Name	1966	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	Totals
Whale	[redacted]	0	0	0	0	[redacted]	0	[redacted]	[redacted]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	[redacted]
South Whale	[redacted]	0	0	0	0	[redacted]	[redacted]	[redacted]	0	0	0	0	0	0	0	0	0	0	0	0	0	[redacted]	0	0	0	0	0	0	0	0	0	0	0	0	[redacted]
Horseshoe	0	0	0	0	0	0	[redacted]	0	[redacted]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	[redacted]
Carson	0	0	0	0	0	0	0	[redacted]	[redacted]	0	0	0	0	0	0	0	0	0	0	0	[redacted]	0	0	0	0	0	0	0	0	0	0	0	0	0	[redacted]
Bonnition	0	0	0	0	0	0	0	[redacted]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	[redacted]
Jeanne d'Arc	0	0	0	0	0	[redacted]	[redacted]	[redacted]	[redacted]	0	0	0	0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0	0	0	0	0	[redacted]	[redacted]	[redacted]	[redacted]
Ridge Complex	0	0	0	0	0	0	0	0	[redacted]	0	0	0	0	0	[redacted]	0	[redacted]	[redacted]	0	[redacted]	[redacted]	0	[redacted]	0	0	0	0	0	0	0	0	0	0	0	[redacted]
Flemish Pass	0	0	0	0	0	0	0	0	0	0	0	0	0	[redacted]	0	0	0	0	0	[redacted]	[redacted]	0	0	0	0	0	0	0	0	0	0	0	0	0	[redacted]
East Nfld./ Orphan	0	0	0	0	0	0	0	0	[redacted]	[redacted]	0	0	0	[redacted]	0	[redacted]	[redacted]	0	0	[redacted]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	[redacted]
St. Anthony	0	0	0	0	0	0	0	0	0	0	[redacted]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	[redacted]
Labrador Shelf	0	0	0	0	0	[redacted]	0	[redacted]	[redacted]	[redacted]	[redacted]	0	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	[redacted]
Anticosti	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	[redacted]	[redacted]	[redacted]	[redacted]	0	[redacted]	[redacted]
Bay St. George	0	0	0	0	0	0	0	[redacted]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	[redacted]	[redacted]
Sydney	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	[redacted]
Totals	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

DOES NOT INCLUDE HIBERNIA AND TERRA NOVA DEVELOPMENT WELLS

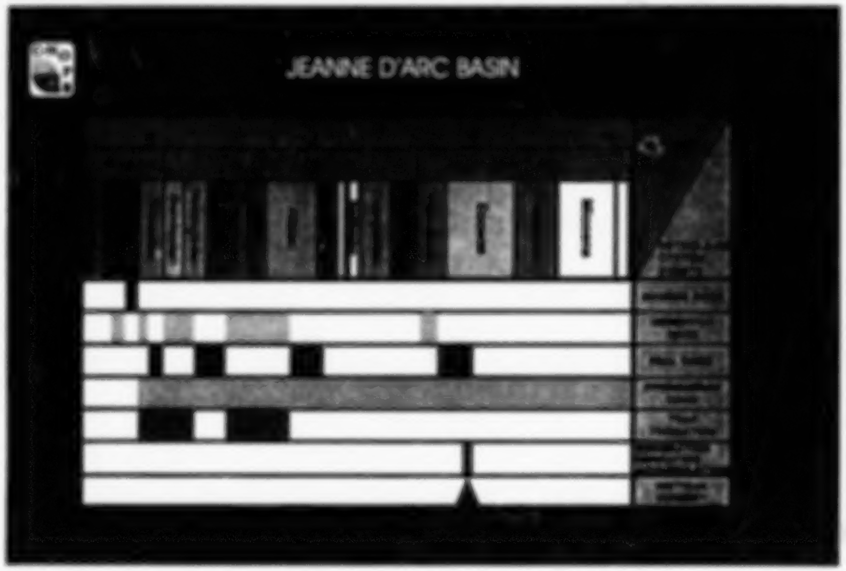
Wells Per Basin Per Year

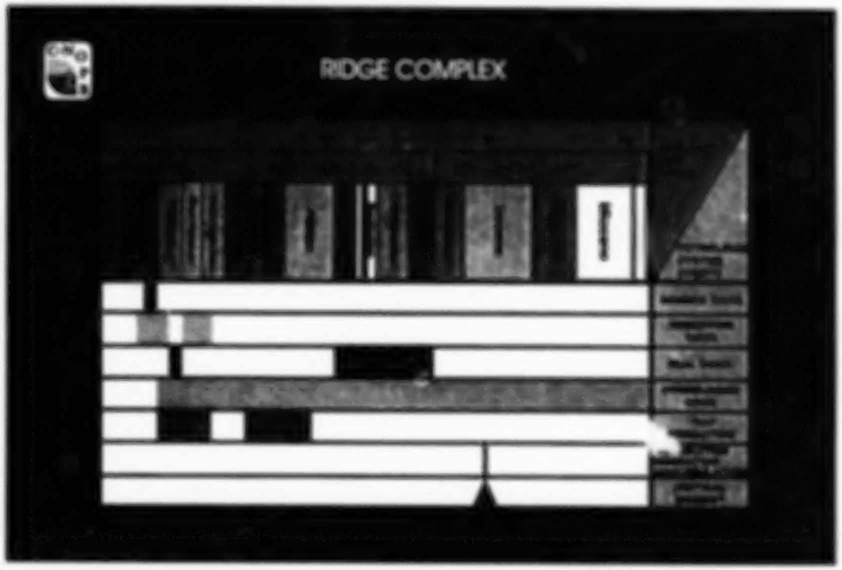
	Year (Spud Date)																																		
Basin Name	1966	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	Totals
Whale	1	0	0	0	0	2	0	5	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10
South Whale	1	0	0	0	0	2	6	5	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	15
Horseshoe	0	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
Carson	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	3
Bonnition	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Jeanne d'Arc	0	0	0	0	0	1	3	3	2	0	0	0	0	1	4	5	1	4	12	8	3	4	6	1	1	2	0	0	0	0	0	1	1	6	69
Ridge Complex	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	2	1	0	1	2	0	1	0	0	0	0	0	0	0	0	0	0	0	9
Flemish Pass	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	3
East Nfld / Orphan	0	0	0	0	0	0	0	0	1	1	0	0	0	2	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
St. Anthony	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Labrador Shelf	0	0	0	0	0	1	0	2	1	5	3	0	3	3	5	2	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	28
Anticosti	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	1	0	1	6
Bay St. George	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2
Sydney	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Totals	2	0	0	0	0	6	11	18	9	6	4	0	3	7	10	8	5	7	12	11	7	5	7	1	1	2	0	0	1	1	2	2	1	8	157

DOES NOT INCLUDE HIBERNIA AND TERRA NOVA DEVELOPMENT WELLS

APPENDIX B
PETROLEUM SYSTEMS EVENTS

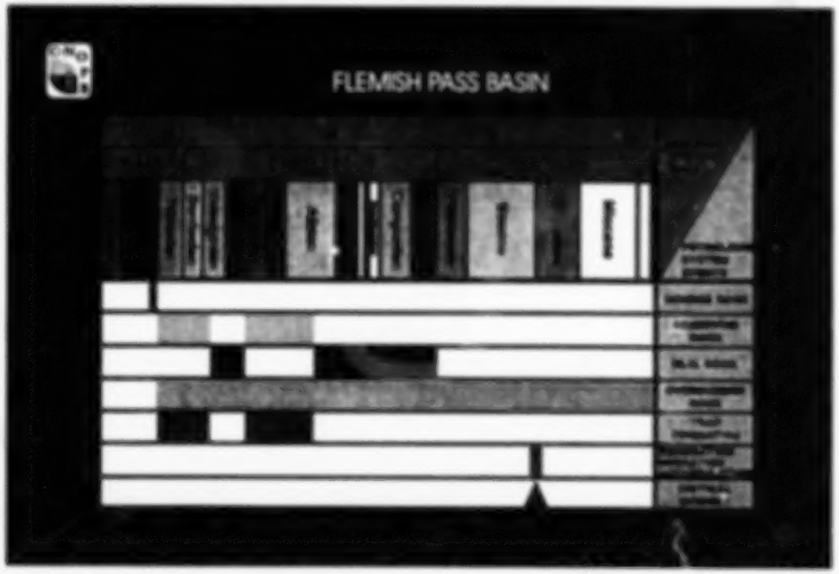
PETROLEUM SYSTEMS EVENTS





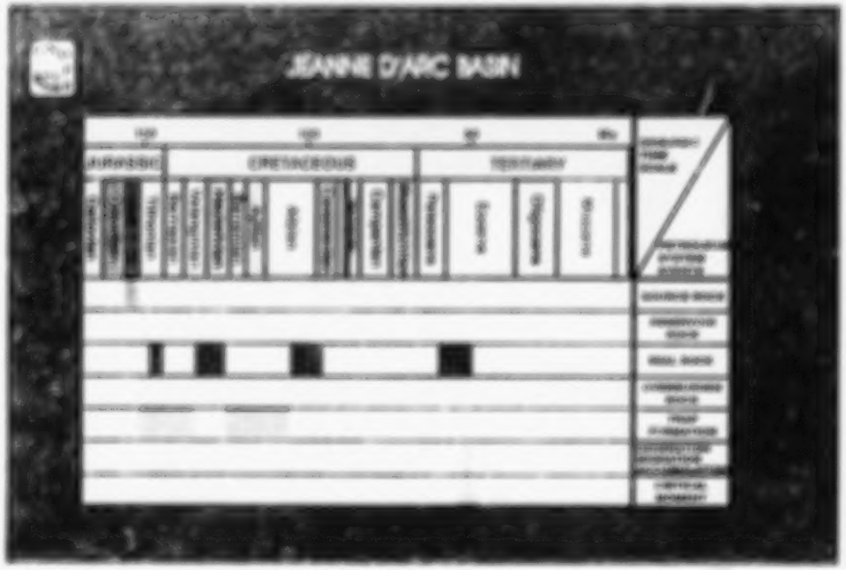
These figures summarize critical data on key sedimentary basins in Newfoundland and Labrador. (DeSilva, 1999)

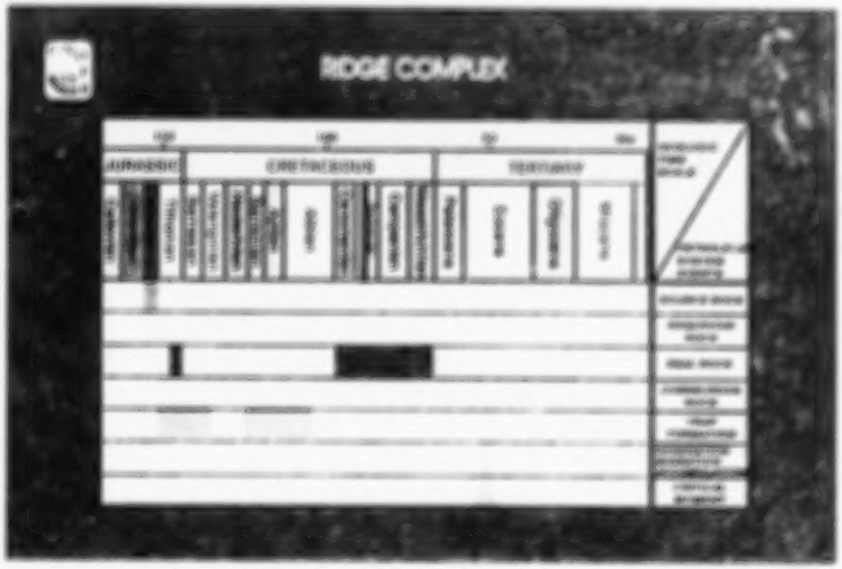
The "critical moment" is the point in time that best depicts the generation, migration, and the accumulation of most hydrocarbons in a petroleum system.



After Desilva, 1999

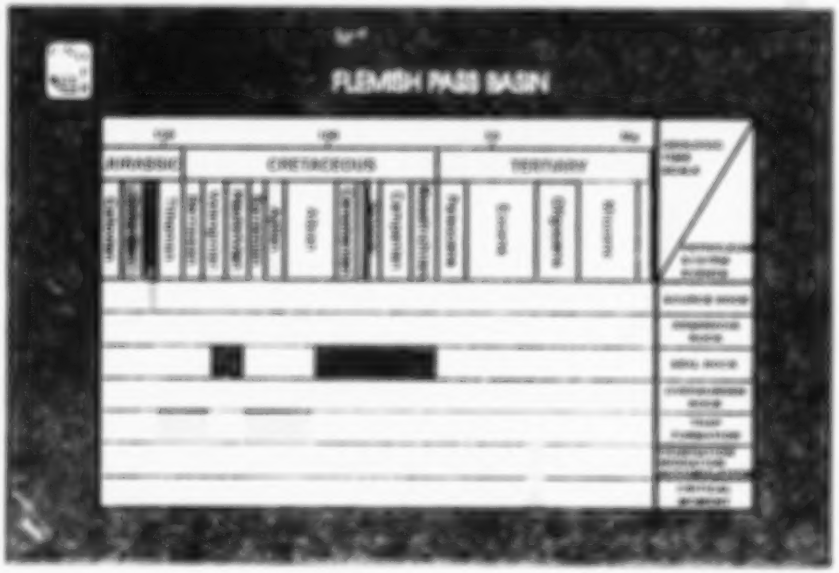
PETROLEUM SYSTEMS EVENTS


JEANNE D'ARC BASIN


RIDGE COMPLEX

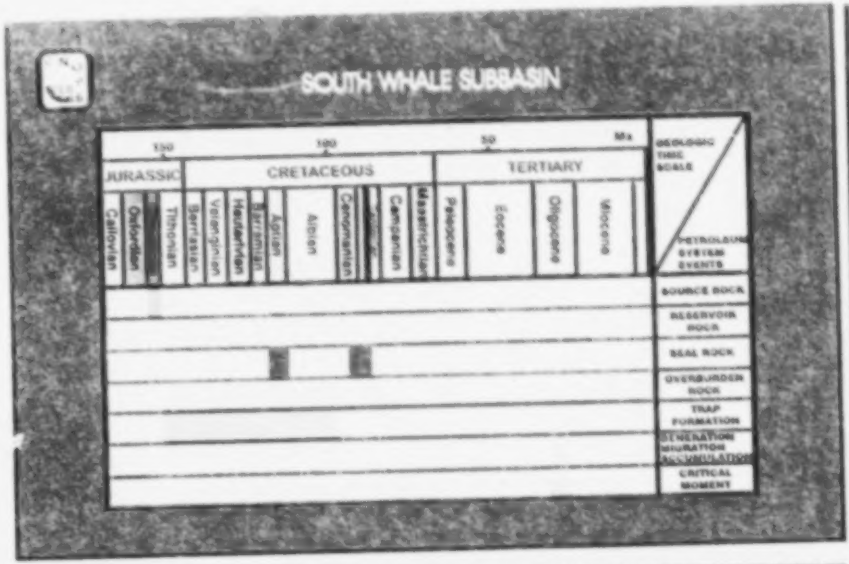
These figures summarize critical data on key sedimentary basins in Newfoundland and Labrador. (DeSilva, 1999)

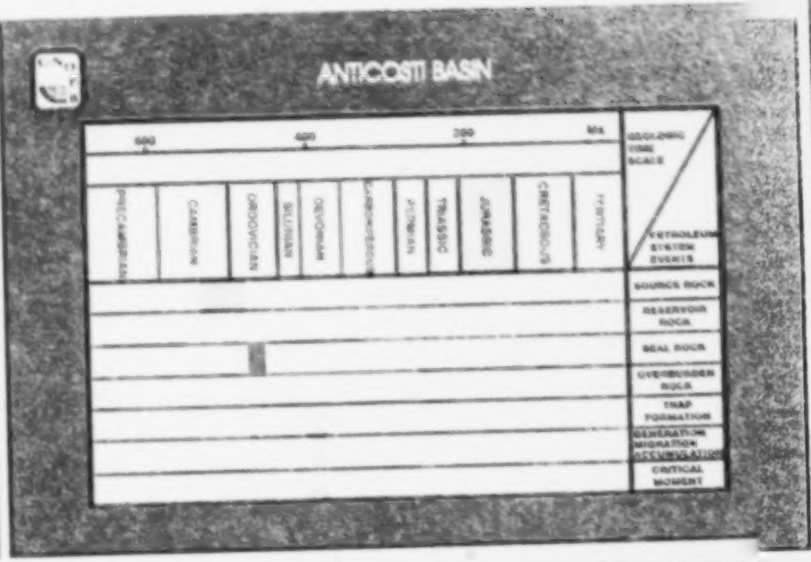
The "critical moment" is the point in time that best depicts the generation, migration, and the accumulation of most hydrocarbons in a petroleum system.

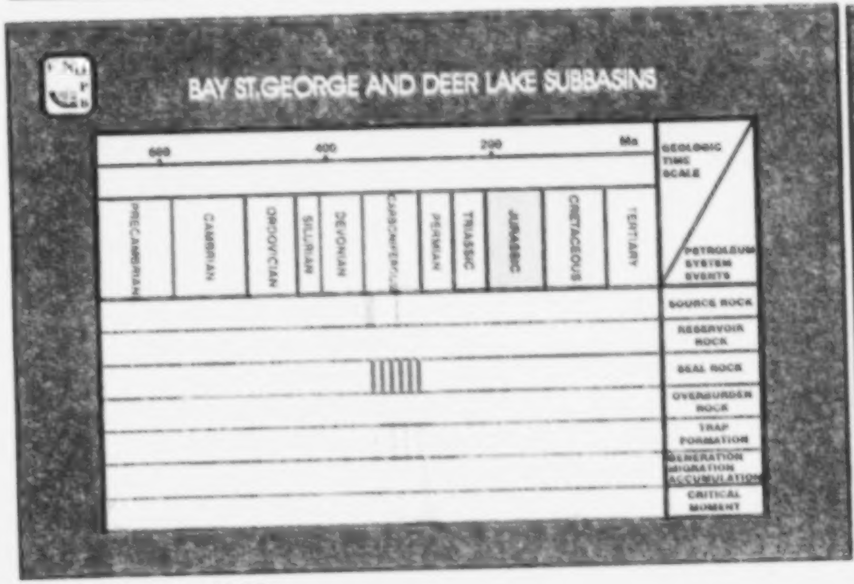

FLEMISH PASS BASIN

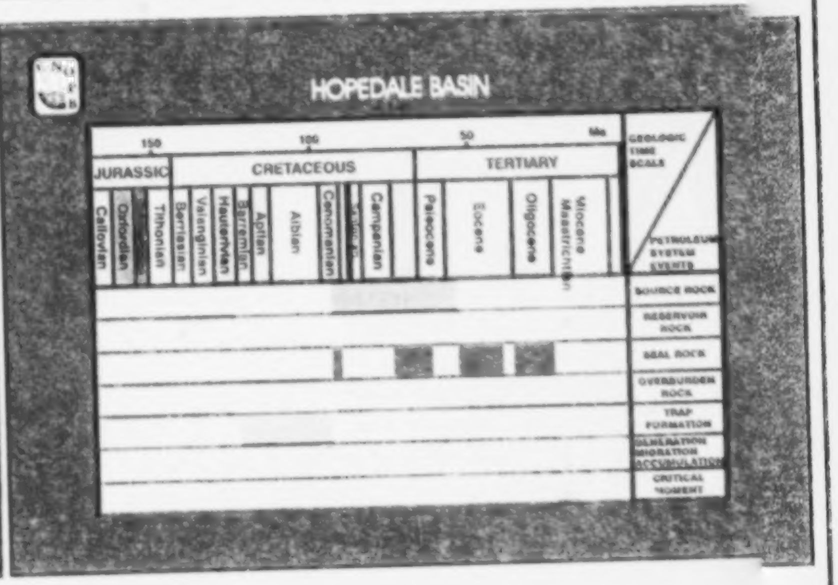
After Desilva, 1999

PETROLEUM SYSTEMS EVENTS


SOUTH WHALE SUBBASIN


ANTICOSTI BASIN


BAY ST.GEORGE AND DEER LAKE SUBBASINS


HOPEDALE BASIN

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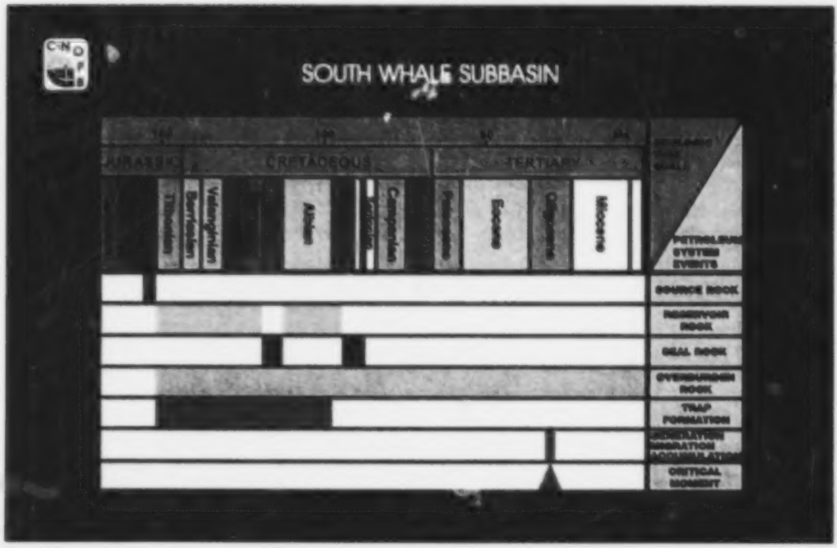
PETROLEUM SYSTEMS EVENTS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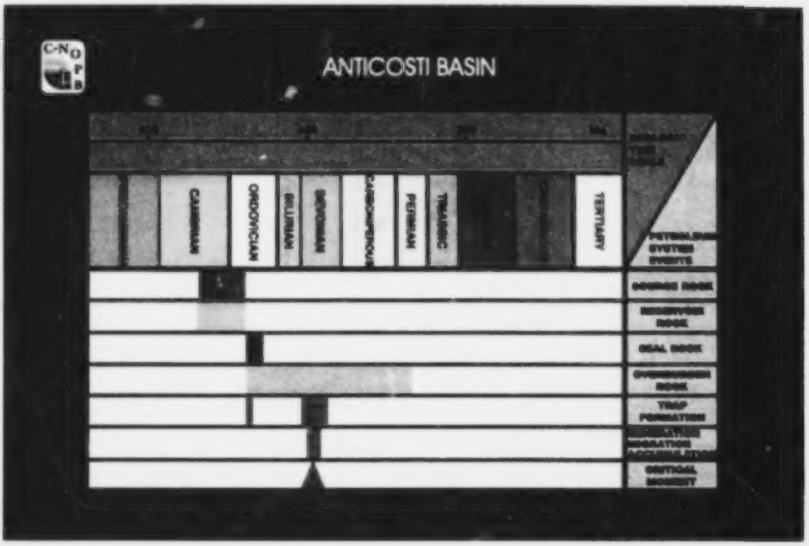
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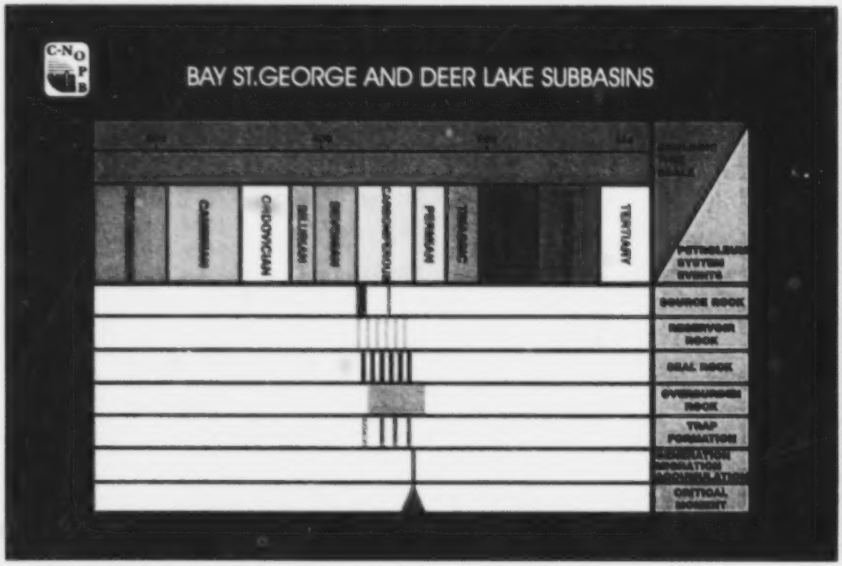
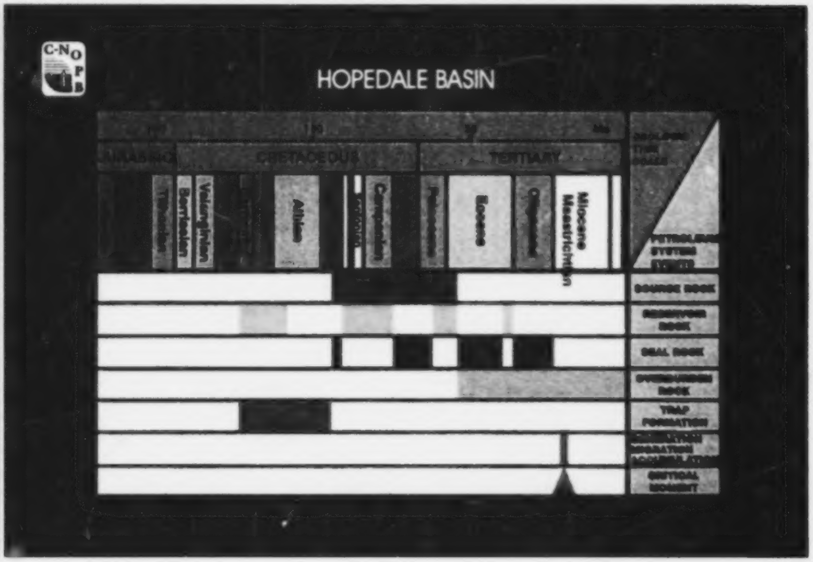

BAY ST.GEORGE AND DEER LAKE SUBBASINS


HOPEDALE BASIN

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